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PHOSPHATE REMOVAL BY ACTIVATED SLUDGE AMENABILITY STUDIES AT INDIANAPOLIS, INDIANA

L. H. Myers, et al

Robert S. Kerr Water Research Center
Ada, Oklahoma

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U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
ROBERT S. KERR WATER RESEARCH CENTER
ADA, OKLAHOMA

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PHOSPHATE REMOVAL BY ACTIVATED SLUDGE

Amenability Studies at Indianapolis, Indiana

by

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ABSTRACT

Phosphate removal by activated sludge was investigated in pilot and plant scale research conducted at the Indianapolis, Indiana, Southwest Sewage Treatment Plant. These studies show that the aeration tanks were averaging 20 percent removal of the orthophosphate in the tank influent. The conditions were different from those found in the San Antonio Rilling Plant:[1]

1. Primary effluent BOD and orthophosphate (as P) levels were much lower, averaging 90 and 5.5 mg/l, respectively;

2. MLSS concentrations were higher, ranging from 1,500 to 1,800 mg/l;

3. BOD loadings were much lower, ranging from 0.09 to 0.16 lb/lb·MLSS/day; and

4. Final clarifiers had deeper sludge blankets and lower dissolved oxygen concentrations, and the mixed liquor aeration time and dissolved oxygen concentrations exceeded those normally found in the Rilling Plant.

Pilot investigations were made to determine the amenability of the waste and activated sludge to phosphate removal. Removal gradually increased with increasing oxygen demanding substrate or hardness concentration. Ferrous iron or aluminum salts removed high levels of orthophosphate, which agrees with previous studies.[2,3] Variation in MLSS or orthophosphate concentration did not cause a significant change in removal in contradiction of previous studies.[2,3] Following an acclimation period of 16 to 40 hours, orthophosphate removal increased to 78 percent which, excluding the chemical addition studies, was the maximum removal efficiency obtained. The waste and sludge were classified as moderately amenable to phosphate removal.

The plant is recommended to demonstrate phosphate removal.

INTRODUCTION

Research studies conducted at San Antonio, Texas,[1,2] indicated the ability of the activated sludge process to remove a high percentage of orthophosphate from municipal and industrial sewage. The investigation concluded that mixed liquor suspended solids in the aeration tanks were capable of removing phosphorus from the soluble phase. The removal capability of this process was dependent upon detention time, biochemical oxygen demand (BOD) loading, mixed liquor suspended solids and dissolved oxygen concentrations, phosphate loading, rapid solid-liquid separation in the final clarifier, fast transfer of return sludge to the aeration tank, and separate disposal of waste phosphate-laden sludge.

As a part of a continuing research program to investigate phosphate removal capabilities by activated sludge plants in different regions of the United States, under different loading and climatic conditions, a study was initiated at the Southwest Sewage Treatment Plant, Indianapolis, Indiana.

The purposes of this and other studies were:

1. To determine the feasibility of phosphate removal by activated sludge plants located in different regions of the United States. These plants, operating under differing conditions due to populations served, mixed wastes from industries and municipal applications, and different properties of the potable water supply represent problems encountered in sewages and their effect on the phosphate removal capabilities of the activated sludge process.

2. To locate a minimum of six activated sludge plants in different regions of the United States capable of demonstrating phosphate removal in the activated sludge process by the parameters identified in the San Antonio study.[2]

3. To locate one activated sludge plant, representing mixed sewage with the operational and design flexibility possible to further study the phosphate removal process with respect to future engineering design.

4. To validate the phosphate removal parameters identified by the San Antonio study.[2] The use of the aerated jugs under control conditions is ideally suited to verify these parameters and to aid in the search for new parameters.

Prior pilot studies[2,3] demonstrate the use of five-gallon polyethylene carboys in representing aeration tanks on a pilot scale. Control of operating parameters during the studies is a must, and these controls are possible by using the carboys. Of importance in the phosphate removal process is the control of dissolved solids concentrations, suspended solids levels, phosphate variations, chemical additions, dissolved oxygen, BOD loading, and aeration time.

The pilot studies, in conjunction with a plant survey, are undertaken to meet the described purposes and may be used in design and operation changes to control phosphate levels in a specific plant effluent.

Experimental Procedures

Plant Analysis

Design, operation, sampling, and analytical procedures concerning the Southwest plant were discussed with the plant superintendent and plant personnel. The plant records were reviewed for sewage flow, BOD loading and removal, total suspended solids levels, air flow rates, and other pertinent chemical and physical parameters. Operating data during this study period obtained from the plant chemist are found in Appendix II.

Tracer studies were conducted using Rhodamine WT* dye on the aeration tanks and final clarifiers to determine characteristics such as detention, short circuiting, and degree of longitudinal mixing.

Grab samples were collected throughout the plant to determine orthophosphate removal, dissolved oxygen concentrations, and total and volatile suspended solids levels. The slug-flow method of sampling was normally used to compensate for process flow-through time.

Samples were transported to the Robert S. Kerr Water Research Center for further analyses to characterize the wastes. These analyses included metals, chemical oxygen demand (COD), total phosphate, sulfate, organic nitrogen, nitrite, and nitrate. When needed, the samples were fixed in accordance with Standard Methods.[4] Analytical procedures are described in Appendix I. Sampled sources were: raw, primary effluent, various points throughout the aeration tanks, return sludge, and final effluent.

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*LBS Rhodamine WT Solution (20%), E. I. DuPont de Nemours Company, Organic Chemicals Department, Dye and Chemical Division, de Nemours Building, Wilmington, Delaware 19898.

Aeration Jug Studies

To obtain the desired range of total suspended solids in the five-gallon polyethylene carboys, a mixed liquor was synthesized. Return sludge or plant mixed liquor was mixed with primary effluent or raw sewage to obtain the desired suspended solids levels. To produce a consistent suspended solids charge for each jug, the return sludge was thickened by a pilot air flotation device. The total suspended solids concentration of the return sludge was estimated by centrifuging 10 ml for 5 minutes and comparing the compacted volume to the measured total suspended solids. Thereafter, centrifugation provided an estimate of TSS. All jugs were started at the same time. The thickened return sludge was kept under aeration until used as the makeup for the jugs.

A portable electric air compressor provided air for the jugs. The air was delivered through a manifold containing individual needle valves for each jug. Rotometers measuring liters of air per minute were connected to the valves, and the controlled air was directed to the bottom of the jugs and out through polyethylene tee fittings which simulated diffusers. Air flow was constant through each study period except where noted.

The jugs were monitored for dissolved oxygen concentration and temperature by immersing a dissolved oxygen meter probe in each jug during the study.

At predetermined intervals, samples were withdrawn from the jugs for chemical analysis. The sample was withdrawn through a plastic tube into a clean and dry four-ounce polyethylene bottle. The first sample was returned to the respective carboy, and a second sample was withdrawn for the desired analysis. If supplemental analyses were desired, a 250 ml sample was taken.

RESULTS AND DISCUSSIONS

Plant Characteristics

The Southwest Indianapolis Water Pollution Control Plant is a 28 mgd activated sludge plant which treats the excess flows from the main Indianapolis Water Pollution Control Plant. The Southwest Plant receives about 20 percent of the total sewage flow from the city of Indianapolis. Sewers in the city of Indianapolis carry both sanitary wastes and storm water flows.

Significant industrial waste contributions include those from the processing of starch, penicillin, meats, and poultry. Industry minimizes such contributions; however, the plant is occasionally upset by slugs of such wastes. The organic loading (BOD) contributed by industry is estimated at 50 percent.

The Southwest Plant, completed in June 1966, is located approximately 10 miles southwest of downtown Indianapolis. An expansion program is under way which will provide a parallel plant of equal capacity. Operation of the existing plant will not be interrupted except during connection of the new plant to the existing raw sewage lift station.

All of the sewage flow from the city of Indianapolis passes through the screens and grit chambers of the main plant. About 25 mgd of this sewage is then pumped through a 10-mile interceptor sewer to the Southwest Plant with a travel time of two hours. Treatment facilities at the Southwest Plant provide screening, grit and scum removal, primary settling, and biological removal by the activated sludge process. The removal of total suspended solids and BOD throughout the plant consistently exceeds 90 percent. The plant effluent discharges into the White River. Figure 1 is a schematic drawing of the treatment units.

Primary clarification facilities consist of four circular units; each has a 95-foot diameter and a 10-foot side wall depth. Primary effluent flows by gravity from the clarifiers into an aerated channel. Gate control structures regulate the channel flow into each aeration tank.

The aeration units consist of four 4-pass, rectangular tanks. Each pass is 188.5 feet long, 30 feet wide, and 15 feet in liquid depth. Piping is available to allow step feeding of primary effluent at the one-quarter points and the inlet end. Aeration is accomplished by coarse diffuser tubes mounted on "swing" headers which are positioned uniformly along the tank length. Seven blowers having a total capacity of 50,000 cfm provide the process air. Final clarification consists of four circular tanks, each 100 feet in

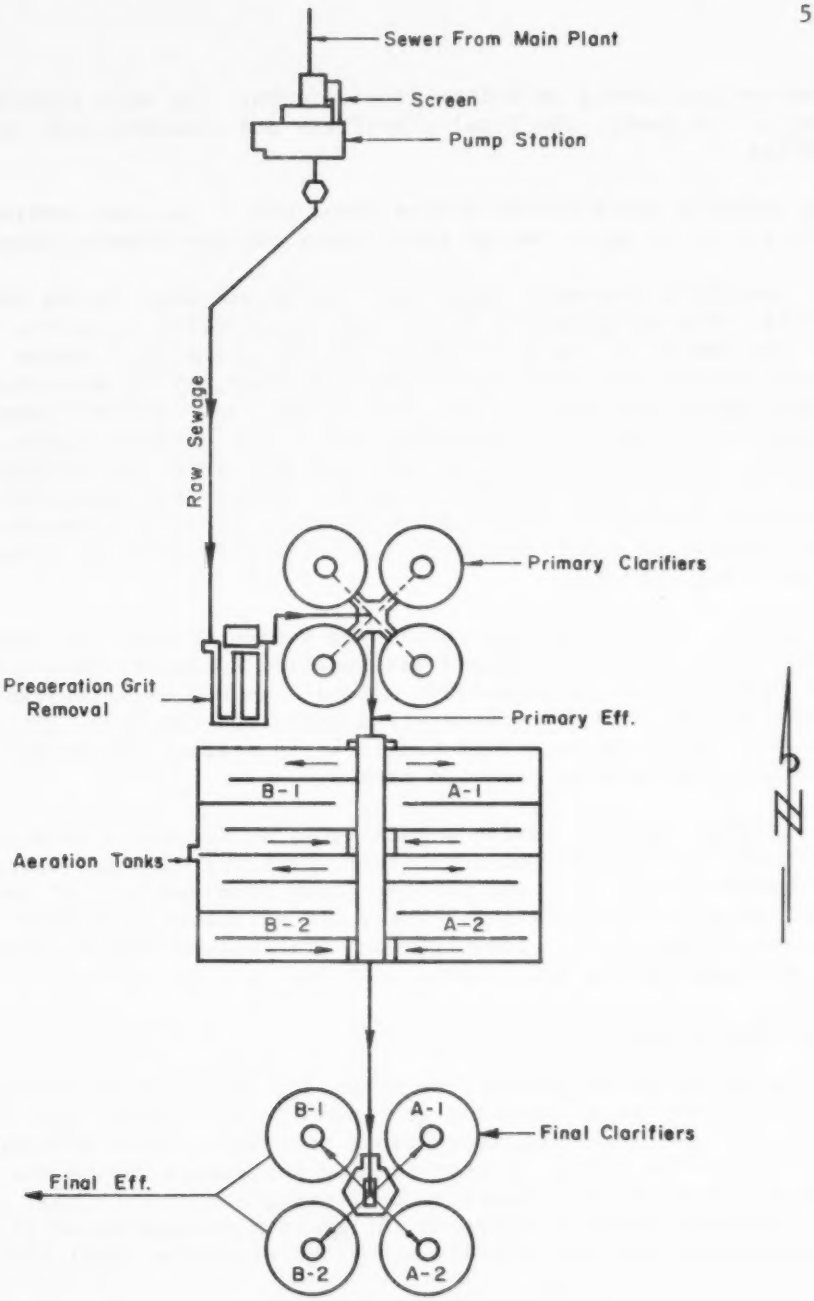

FIGURE 1 – SOUTHWEST SEWAGE TREATMENT PLANT
INDIANAPOLIS, IND.

diameter and having an 8-foot liquid depth. The weir length of each tank is 314 feet. The final clarifiers are equipped with inlet baffles.

Six variable speed return sludge pumps have a maximum combined capacity of 21 mgd. Two of these pumps are for standby purposes.

The secondary treatment facilities can be operated as two independent plants. The 14 mgd plant on the east is referred to as the "A" plant, and the one on the west is called the "B" plant (See Figure 1). The return sludge flow from each final clarifier may be monitored at the sludge wells adjacent to the final clarifiers. Return sludge is pumped back directly to the inlet end of the aeration tanks. If desired, return sludge can be diverted and mixed with primary effluent prior to entering the aeration tanks. During such diversion, the secondary facilities could not be divided into two independent plants. Step feeding is practiced when slugs of waste upset the conventional flow-through process.

Indicating, recording, and totalizing meters monitor (1) total raw sewage flow, (2) the combined air supplied to Passes Nos. 1 and 2 and that supplied to Passes Nos. 3 and 4 in the aeration tanks, (3) return sludge flow to each aeration tank, and (4) waste activated sludge. There are no meters available to measure the primary effluent flow to each aeration tank.

Nine sludge lagoons, having a total area in excess of 45 acres, are available for disposal of screenings, grit, primary and waste activated sludge, oil, and grease. Less than one-half of the lagoon area contains this material. There was no return flow from the lagoons to the plant. These lagoons are located west of the plant and adjacent to the White River.

Plant Monitoring

During the study period of June 12 to 21, 1967, the "B"-battery aeration tanks were operating in conventional flow-through fashion while the "A"-battery aeration tanks received primary effluent by step feed. The method of step feeding was varied during the study period. Emphasis was placed on monitoring the conventional process ("B" battery) since it provided the greater average mixed liquor aeration time and more closely simulated plug-flow conditions.

General Plant Operation

Normal sewage flow averages 25 to 28 mgd. Diurnal flow variation was insignificant since it did not exceed 10 percent. The return sludge varied from 53 to 60 percent of the sewage flow. The unit

amount of air applied ranged from 1.7 to 2.7 cu. ft. per gallon of primary effluent. An average of 500,000 gallons or 3.5 percent of the activated sludge was wasted daily.

The MLSS concentrations in the aeration tanks ranged from 1,625 to 2,343 mg/l during the study period. The unit organic loading in the aeration tanks varied from 9 to 16 pounds BOD per 100 pounds of MLSS per day. Return sludge total suspended solids ranged from 2,700 to 4,500 mg/l. The primary effluent had concentrations of BOD and total suspended solids averaging 90 and 85 mg/l, respectively, during the study period. The final effluent contained about 10 mg/l BOD and 15 mg/l total suspended solids. These results were determined by plant personnel utilizing 24-hour composite samples. The average removal of BOD and suspended solids through the activated sludge facilities was 90 and 80 percent, respectively. Plant operation and performance data are given in Appendix II.

Dye Tracer Studies

Flow Distribution - At 12:15 p.m. on June 12, 1967, 10 liters of 20 percent Rhodamine WT dye was added to the primary effluent to determine the flow division and the detention times in the aeration tanks. Samples were collected from the one-half point and effluent of the "B"-battery tanks and from the effluent of the "A"-battery tanks. The comparison of dye recoveries indicated that Aeration Tank B-1 received 29 percent of the sewage flow. Aeration Tanks B-2, A-1, and A-2 received 23, 25, and 23 percent, respectively. These results were used to compute the hydraulic loading to each aeration tank during subsequent studies.

Aeration Tanks (Battery "A") - Figure 2 is a plot of dye concentration versus elapsed time after dye addition on July 12 for the Battery "A" aeration tanks. During this study period, these aeration tanks were operated by step feed with the settled sludge returned to the inlet end of the tank and the primary effluent in equal proportions added to the one-quarter and one-half points. The average flow rates of return sludge and primary effluent are given in Figure 2. The theoretical displacement time of the primary effluent is also shown. Computation of area under the dye curve shows that 8 percent and 34 percent of the primary effluent flow received less than 2 and 3 hours of aeration, respectively.

Aeration Tanks (Battery "B") - At 9:00 a.m. on June 15, 2.5 liters of 20 percent Rhodamine WT dye was added at the inlet of Aeration Tank B-2 to determine its hydraulic characteristics. Primary effluent and return sludge entered only the inlet, and samples were collected from the one-half and outlet points of this tank. Samples were also collected from the one-half and effluent points of Aeration Tank B-1

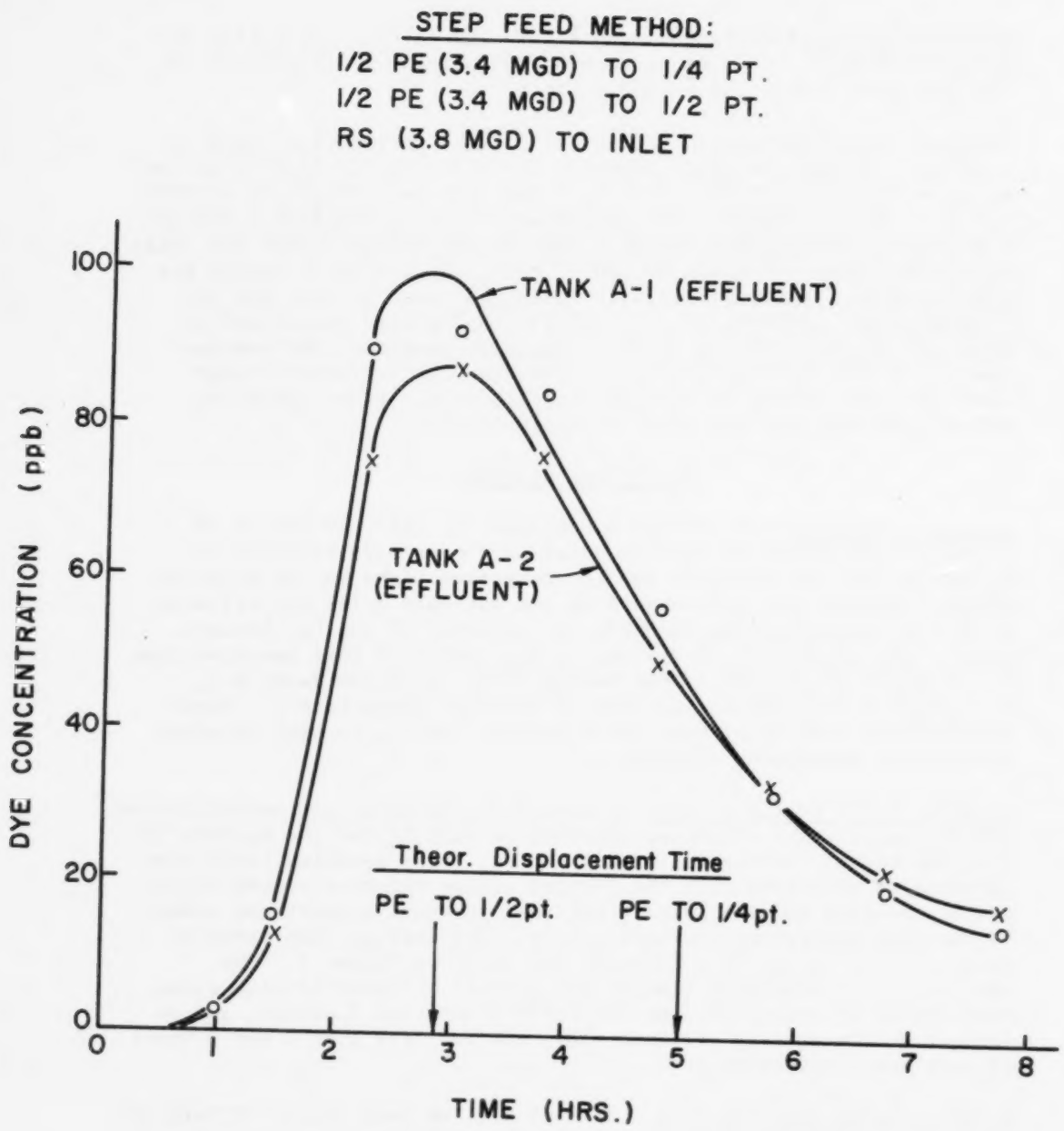

FIGURE 2 - DYE DETENTION IN AERATION TANKS - STEP FEED

to determine the background dye concentration caused by the return of dyed sludge to the aeration tanks. Sampling was discontinued at 8:00 p.m. since the effluent dye concentration was approaching the background concentration. These study results were used in preference to those of June 12 because correction was made for background dye concentration.

The average mixed liquor flow rate through the 2.5 million-gallon aeration tank was 9.9 mgd during the study; therefore, the theoretical displacement time was 6.1 hours. Flow did not vary significantly during the study. The four-pass aeration tank has a length to width ratio of 25:1. The average amount of air applied was 10,100 cfm or 1.5 cu. ft. per gallon of mixed liquor. Dye concentration above background at the one-half and outlet points versus elapsed time after dye addition is plotted in Figure 3 along with a percent flow-through curve. The modal and median detention times were 4.8 and 5.4 hours, respectively. The times of 10 percent (t_{10}) and 90 percent (t_{90}) flow through were 3.5 and 7.9 hours, respectively, which resulted in a dispersion index (t_{90}/t_{10}) of 2.25. The modal detention time (t_M) is equal to 78 percent of the theoretical displacement time (t_d). The dye recovery was within 10 percent of the amount added.

The corresponding value of t_{90}/t_{10} for the aeration tanks of the San Antonio Rilling Plant[2] was 3.5. This indicates that the Indianapolis aeration tanks exhibit less longitudinal mixing and better plug-flow characteristics than do the Rilling tanks. Since the Indianapolis tanks are four-pass with a 25:1 length to width ratio as compared to two-pass with a 20:1 length to width ratio for the Rilling tanks, the physical configuration of the Indianapolis tanks is more favorable to plug-flow simulation. Referring to Figure 3, the flow-through characteristics of the Indianapolis B-aeration tanks are such that all of the flow receives at least two hours' aeration, and only 3 percent receives less than 3 hours' aeration.

The rates of phosphate removal observed in pilot and plant investigations[1,2] indicate that the hydraulic characteristics of the Indianapolis aeration tanks are adequate for phosphate removal. Although plug-flow characteristics are diminished by step feeding (split equally between the one-quarter and midpoints), detention times are sufficient to allow phosphate removal.

Final Clarifiers - At 1:45 p.m. on June 19, 0.5 liter of 20 percent Rhodamine WT dye was added to the inlet well of Final Clarifier B-2 to determine the flow-through characteristics of the overflow and return sludge. Samples of the clarifier overflow were collected at 5- to 30-minute intervals. The return sludge was sampled at the adjacent sludge well. Dye concentration versus elapsed time after dye addition for both the overflow and the return sludge are depicted in Figure 4.

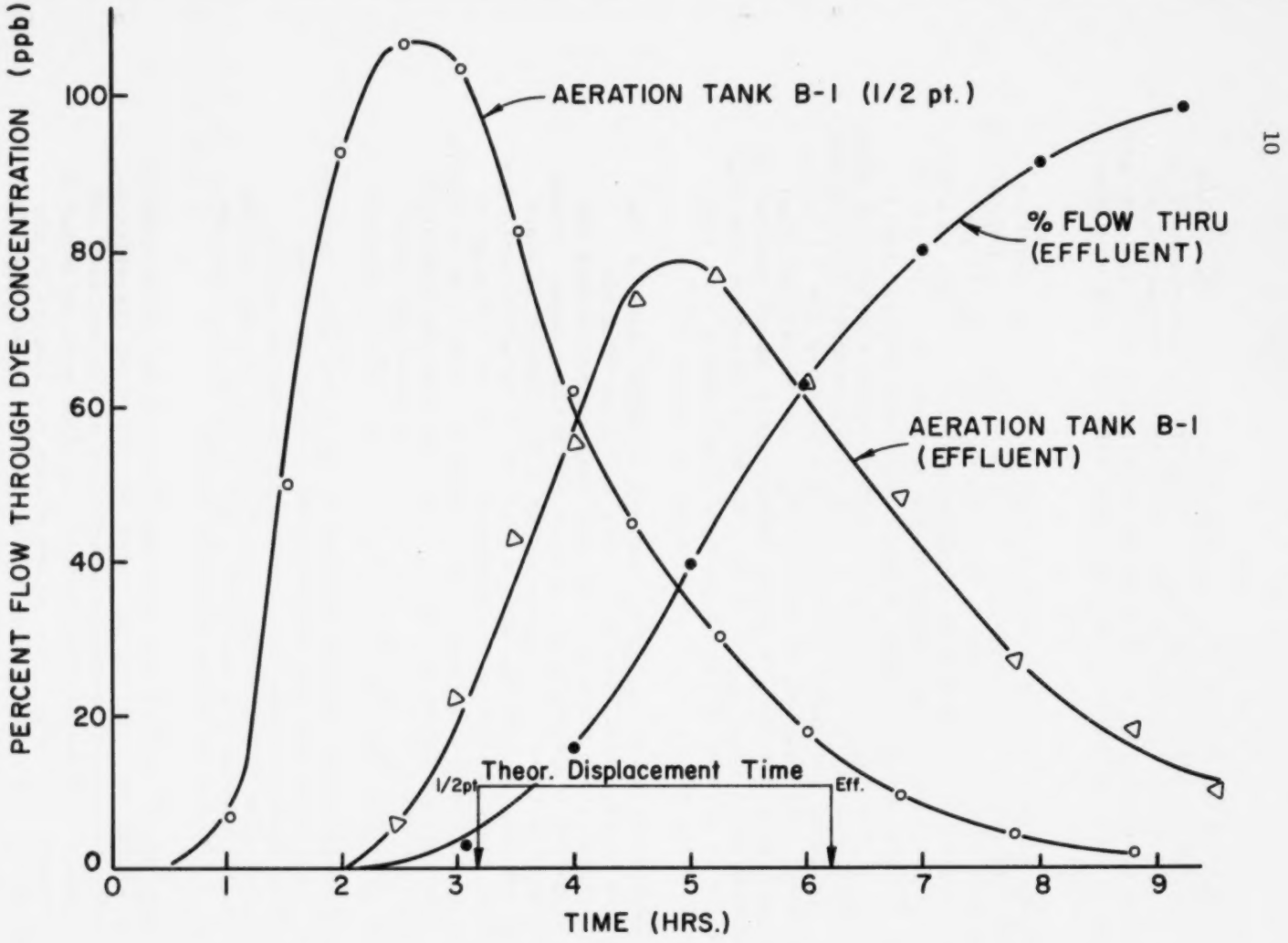

FIGURE 3 - DYE DETENTION IN AERATION TANKS — CONVENTIONAL FEED

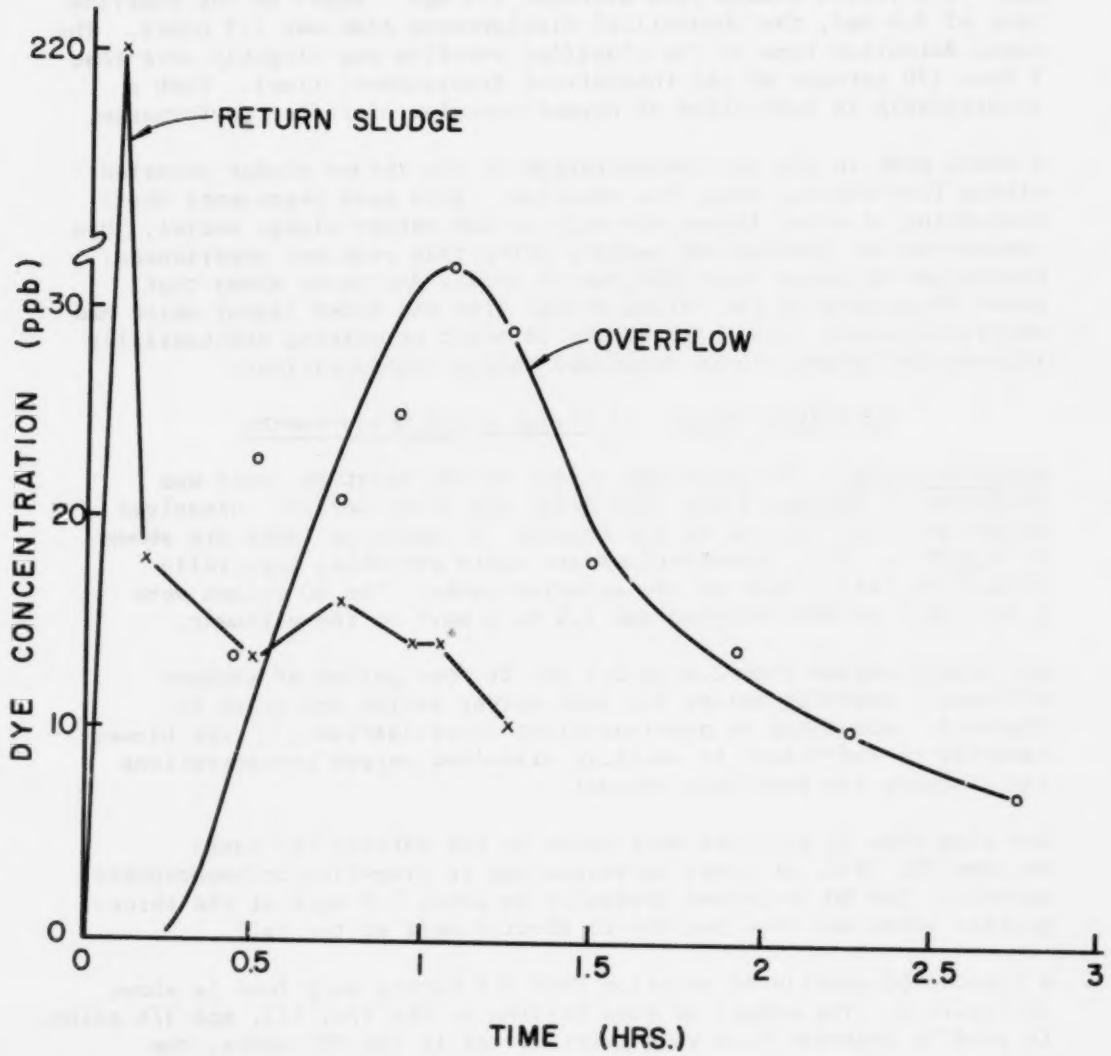

FIGURE 4 – DYE DETENTION IN FINAL CLARIFIERS

Assuming an equal flow split between the "B"-battery clarifiers, the average mixed liquor inflow to the 470,000-gallon clarifier was 11 mgd. The return sludge flow averaged 3.6 mgd. Based on the overflow rate of 7.4 mgd, the theoretical displacement time was 1.5 hours. The modal detention time of the clarifier overflow was slightly more than 1 hour (70 percent of the theoretical displacement time). Such a relationship is indicative of normal circular clarifier performance.

A sharp peak in the dye concentration of the return sludge occurred within five minutes after dye addition. This peak represents short circuiting of mixed liquor directly to the return sludge outlet. Dye concentrations dropped off rapidly after this peak was experienced. Comparison of areas under the return sludge dye curve shows that about 50 percent of the return sludge flow was mixed liquor which had short-circuited. This high degree of short circuiting substantially reduces the return sludge suspended solids concentrations.

Dissolved Oxygen and Sludge Depth Measurements

Aeration Tanks - The dissolved oxygen in the aeration tanks was monitored at various times throughout the study period. Dissolved oxygen profiles for one of the Battery "B" aeration tanks are shown in Figure 5. The concentrations are quite variable, especially during the latter half of the aeration tanks. The DO values were 1 to 2 mg/l at the midpoint and 2.5 to 4 mg/l at the effluent.

Air supply varied from 2.0 to 2.7 cu. ft. per gallon of primary effluent. Specific values for each survey period are shown in Figure 5. According to previous plant investigations,[1,3] the blower capacity is sufficient to maintain dissolved oxygen concentrations satisfactory for phosphate removal.

Two slug-flow DO profiles were taken in the Battery "B" tanks on June 20, 1967, at times corresponding to slug-flow orthophosphate surveys. The DO increased gradually to about 1.5 mg/l at the three-quarter point and then rapidly to about 4 mg/l at the tail.

A typical DO profile of Aeration Tank A-1 having step feed is shown in Figure 6. The effect of step feeding at the 1/4, 1/2, and 3/4 points is readily apparent from this profile. As in the "B" tanks, the DO rapidly increased during the last quarter of the tank. The dissolved oxygen levels were sufficient for phosphate removal.

Final Clarifiers - The dissolved oxygen in the final clarifiers ranged from 0.5 to 0.9 mg/l. Sludge blanket depths, estimated by use of an optical density sensor, were 12 inches at the side wall and 2 to 4 feet in the center. The plant superintendent has found that such sludge blanket depths cannot be avoided with the present sludge scraper performance. The return sludge dissolved oxygen concentration varied from 0.2 to 0.6 mg/l. The low DO concentrations

DATE	TIME	PE FLOW	AIR APPLIED	
1967	PM	MGD	CFM	CU.FT/GAL.
6/15	1:00	6.4	10,100	2.28
6/17	4:00	4.8	9,000	2.71
6/19	4:30	6.4	9,100	2.05
6/21	5:30	5.8	10,300	2.55

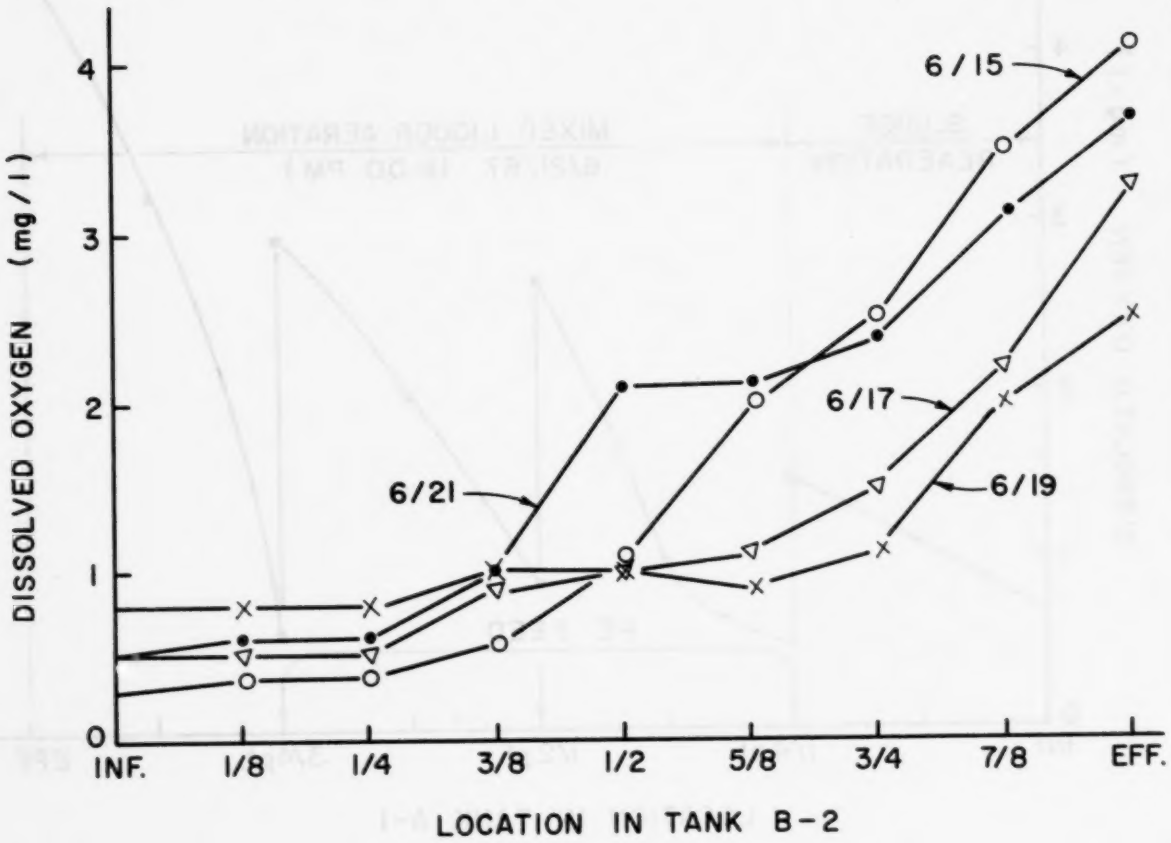

FIGURE 5 - DISSOLVED OXYGEN IN AERATION TANK - CONVENTIONAL FEED

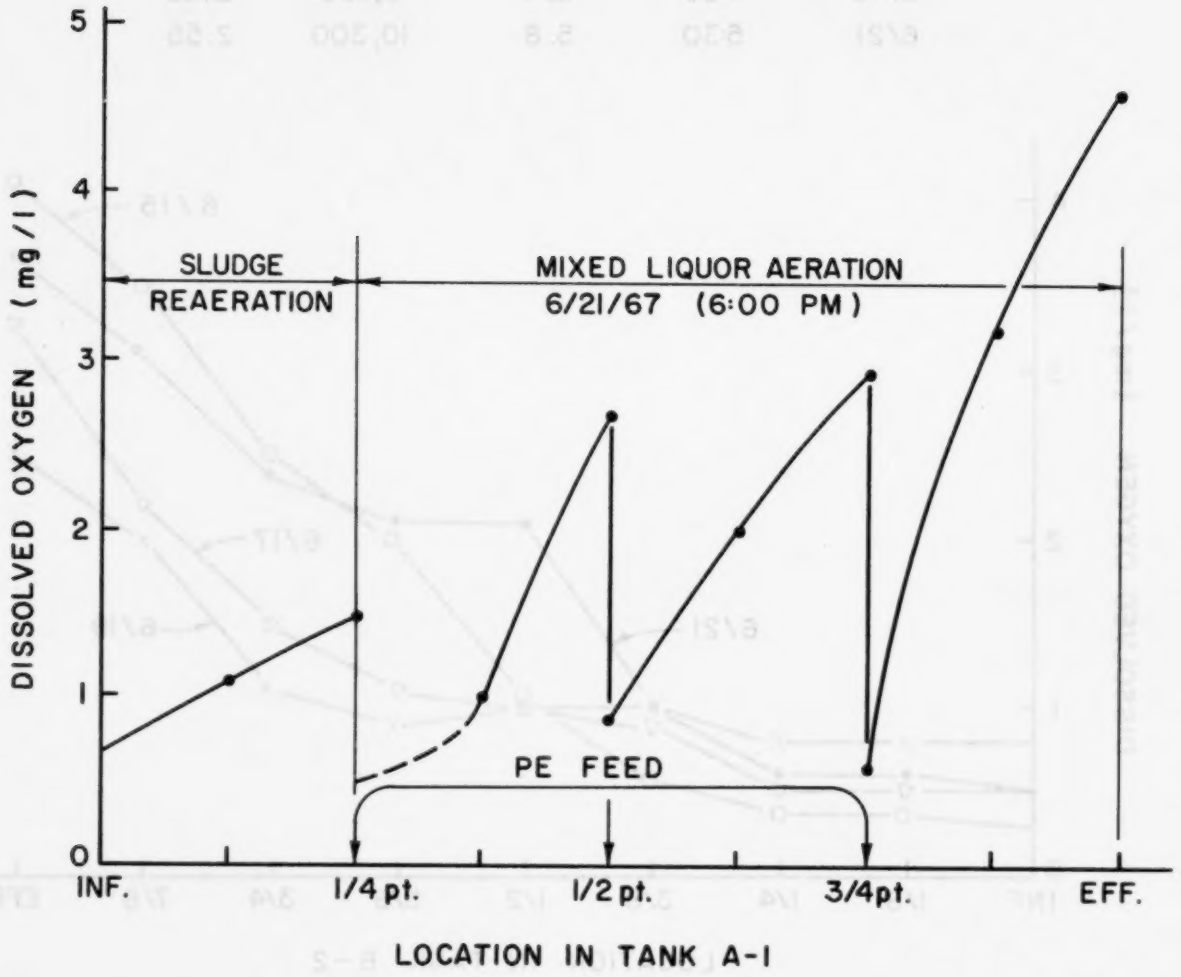

FIGURE 6 - DISSOLVED OXYGEN IN AERATION TANK
STEP FEED

in the final clarifiers are apparently caused by the sludge blanket. Such an environment caused phosphate release as seen by the increase of orthophosphate in the final clarifier.

Phosphate and Solids Monitoring

The plant was monitored to determine phosphate removal and suspended solids concentrations. The raw sewage (raw), primary effluent (PE), return sludge (RS), and final effluent (FE) were sampled along with Aeration Tanks Nos. 1 and 2 in "B" battery (B-1, B-2) at the inlet (in), half-point (1/2), and outlet (out). The data for the "B" plant are shown in Table 1. Many of the samples taken on June 14, 15, 17, and 20 were staggered in proportion to the modal detention times to follow a "slug" of waste through the unit processes.

The plant was not obtaining significant phosphate removal, and a sampling program was not undertaken to more accurately determine removals. From the available data, removals were estimated at 10 percent from the primary to final effluents and at 20 percent through the aeration tanks. The average phosphate as P concentrations of PE and FE were 5.4 and 4.7 mg/l, respectively.

The suspended solids varied from 3 to 5 thousand mg/l in the return sludge and from 1.5 to 2 thousand mg/l in the mixed liquor and had a volatile content ranging from 70 to 85 percent.

Aeration Jug Studies

A series of experiments were devised to test the sewage and sludge of selected plants with regard to orthophosphate removal. Factors previously shown[2] to effect the rate and magnitude of orthophosphate removal in the aeration tank are: suspended solids, DO, BOD, and orthophosphate concentrations; concentration of metal precipitants and sludge conditions. These experiments are devised to evaluate plants for future process demonstration.

MLSS Variation

A battery of seven jugs was prepared on June 13, 1967, to determine the optimum mixed liquor suspended solids concentration for soluble phosphorus removal. Jug components used in this study are presented in Table 2.

Table 1

Plant Monitoring - Phosphate and Solids
Southwest Indianapolis Sewage Treatment Plant

Sample	Time	O-PO_4 (mg/l-P)	TSS (mg/l)	VSS (mg/l)
6/12/67				
Raw	2:30 pm	4.8	--	--
PE	2:30 pm	4.6	--	--
RS	2:30 pm	7.0	3290	2820
B-1 (in)	2:30 pm	5.9	--	--
B-1 (1/2)	2:30 pm	5.9	1620	1270
B-1 (out)	2:30 pm	5.4	--	--
FE (B-1)	2:30 pm	5.9	--	--
B-2 (in)	2:30 pm	5.5	--	--
B-2 (1/2)	2:30 pm	5.6	1650	1130
B-2 (out)	2:30 pm	5.2	1620	1140
FE (B-2)	2:30 pm	5.8	--	--
6/13/67				
RS	11:30 am	3.0	4030	--
PE	12:00 N	4.8	--	--
FE	12:30 pm	2.8	32	--
6/14/67				
PE	10:30 am	6.0	82	--
FE	10:30 am	4.7	--	--
RS	10:30 am	--	2600	--
RS	12:30 pm	5.5	--	--
RS	6:20 pm	4.9	--	--
B-2 (in)	12:00 N	5.8	--	--
B-2 (1/2)	2:15 pm	5.4	--	--
B-2 (out)	6:15 pm	4.4	--	--
FE	6:25 pm	4.4	--	--
6/15/67				
PE	9:30 am	7.4	--	--
RS	9:30 am	7.3	4890	--
RS	4:00 pm	9.1	--	--
B-1 (in)	9:00 am	--	1600	--
B-1 (1/2)	9:30 am	--	1720	--
B-1 (out)	10:00 am	--	1850	--
B-2 (out)	10:00 am	--	1690	--
B-2 (out)	2:30 pm	5.1	1560	--
B-2 (out)	3:45 pm	5.1	--	--

Sample	Time	O-PO_4 (mg/l-P)	TSS (mg/l)
6/16/67			
PE	9:30 am	4.3	76
PE	6:00 pm	5.3	--
RS	9:45 am	4.2	--
6/17/67			
Raw	2:00 pm	5.5	--
PE	11:30 am	7.0	54
PE	2:00 pm	7.2	--
RS	11:30 am	7.0	--
RS	12:15 pm	--	3080
B (in)	2:00 pm	5.8	--
B (out)	2:00 pm	6.8	--
FE	3:00 pm	7.0	--
6/20/67			
Raw	9:00 am	3.0	248
Raw	10:00 am	3.7	--
PE	10:30 am	4.3	186
PE	11:30 am	4.0	--
PE	4:20 pm	4.4	--
RS	10:30 am	4.3	3800
RS	11:30 am	4.3	--
B-2 (in)	10:30 am	5.4	2010
B-2 (in)	11:30 am	4.8	--
B-2 (1/2)	1:00 pm	3.9	2170
B-2 (1/2)	2:00 pm	4.1	--
B-2 (out)	3:30 pm	4.3	1760
B-2 (out)	4:30 pm	4.0	--
FE	4:20 pm	3.5	--
FE	4:30 pm	3.6	--

Table 2

Mixed Liquor Suspended Solids Variation
Components of Aeration Jugs*

Jug No.	PE (liter)	Conc. RS (liter)	FE (liter)	TSS (mg/l)	VSS (mg/l)
1	10	0.4	4.6	453	268
2	10	0.8	4.2	1,241	608
3	10	1.1	3.9	1,676	932
4	10	1.5	3.5	2,246	1,316
5	10	1.9	3.1	2,470	1,748
6	10	2.6	2.4	3,445	2,130
7	10	3.4	1.6	4,760	3,060

*Aeration rate = 17.5 liters per minute

A constant volume of primary effluent was used in each jug to limit the effect of BOD variation. Final effluent was used to bring the volume of each jug to 15 liters. Analyses of the jug components are given in Table 1, and the study results in Table 3.

Table 3

MLSS Variation - Results
Soluble Orthophosphate (mg/l-P)

Aeration Time (hrs.)	Jug No. 1	2	3	4	5	6	7
0 (12:30 p.m.)	3.8	3.8	3.7	3.8	4.4	4.6	4.4
1	3.0	2.9	2.7	3.0	4.5	3.2	4.8
2	2.8	2.4	2.3	2.3	3.8	2.3	3.2
3	2.0	2.1	2.0	2.0	2.4	2.0	2.2
4	2.2	2.1	2.0	2.0	2.1	2.1	2.2
5	2.1	1.9	1.8	1.9	2.1	1.9	2.1
6	2.0	1.8	1.8	1.9	2.1	2.1	2.3
% Removal	47	52	51	50	52	54	47
TSS (mg/l)	453	1,241	1,676	2,246	2,470	3,445	4,760

Figure 7 illustrates variation of soluble orthophosphate concentration with respect to aeration time. Maximum soluble phosphate removal was accomplished in the first three hours of aeration after which little change was noted. During the study, removals varied from 47 to 54 percent; therefore, it was concluded that suspended solids concentrations in the range studied had no significant effect on phosphate removal. Total suspended and volatile suspended solids concentrations show no correlation with orthophosphate removal. An intermediate MLSS level of 2,500 mg/l was chosen for use in future studies.

The temperature increased from 25 to 30°C during the initial 3-hour aeration period due to absorption of heat from sunshine on the jugs in the afternoon. After 3 hours, the temperature exceeded 30°C.

After 6 hours' aeration, the air supply was terminated, and jug contents were permitted to settle for 30 minutes. Figure 8 shows soluble and total phosphate data for the supernate and settled sludge. The total phosphate is incorporated in the solids and effectively removed by settling. The greater orthophosphate concentration in the sludge compared to that in the supernatant indicates release from the solid to the water in the simulated return sludge. The orthophosphate concentration in the supernate is essentially equal to that in the jug mixed liquor after 6 hours' aeration, indicating no release in the simulated final effluent within the 30-minute quiescent settling period.

Organic Load Variation

A battery of six jugs was prepared on June 14, 1967, to determine the effect of variation in the substrate BOD concentration on orthophosphate removal.

Jugs in this experiment contained solids (2.5 liters of concentrated sludge diluted with an equal volume of final effluent) and a BOD source which will be called substrate to distinguish it from plant primary effluent. This substrate volume was 10 liters for each jug.

Jug No. 2 was the control and contained 10 liters of plant primary effluent as substrate and was the 100 percent reference point.

According to plant records, the average annual BOD of the primary effluent is 150 mg/l. The primary effluent used for jug makeup was assumed to have this BOD concentration.

Substrate BOD load was reduced to about 50 percent in Jug No. 1 by using 5 liters of primary effluent and 5 liters of final effluent. Approximately 125, 165, and 250 percent substrate BOD loads were established in Jugs Nos. 3, 4, and 5, respectively, by the addition

JUG NO.	TSS (mg/l)
1	453
2	1,241
3	1,676
4	2,246
5	2,470
6	3,445
7	4,760

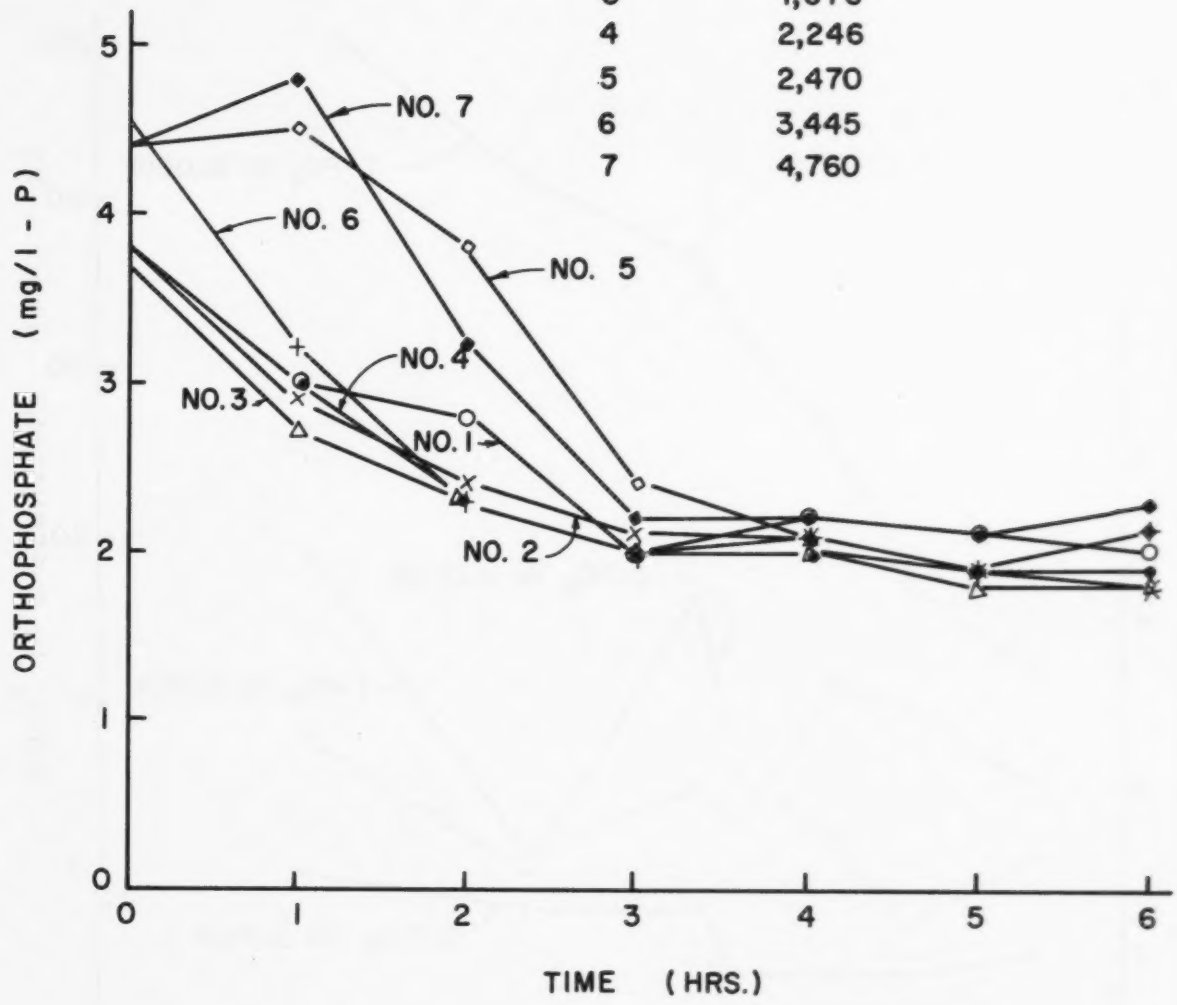

FIGURE 7 - MLSS VARIATION - PHOSPHATE

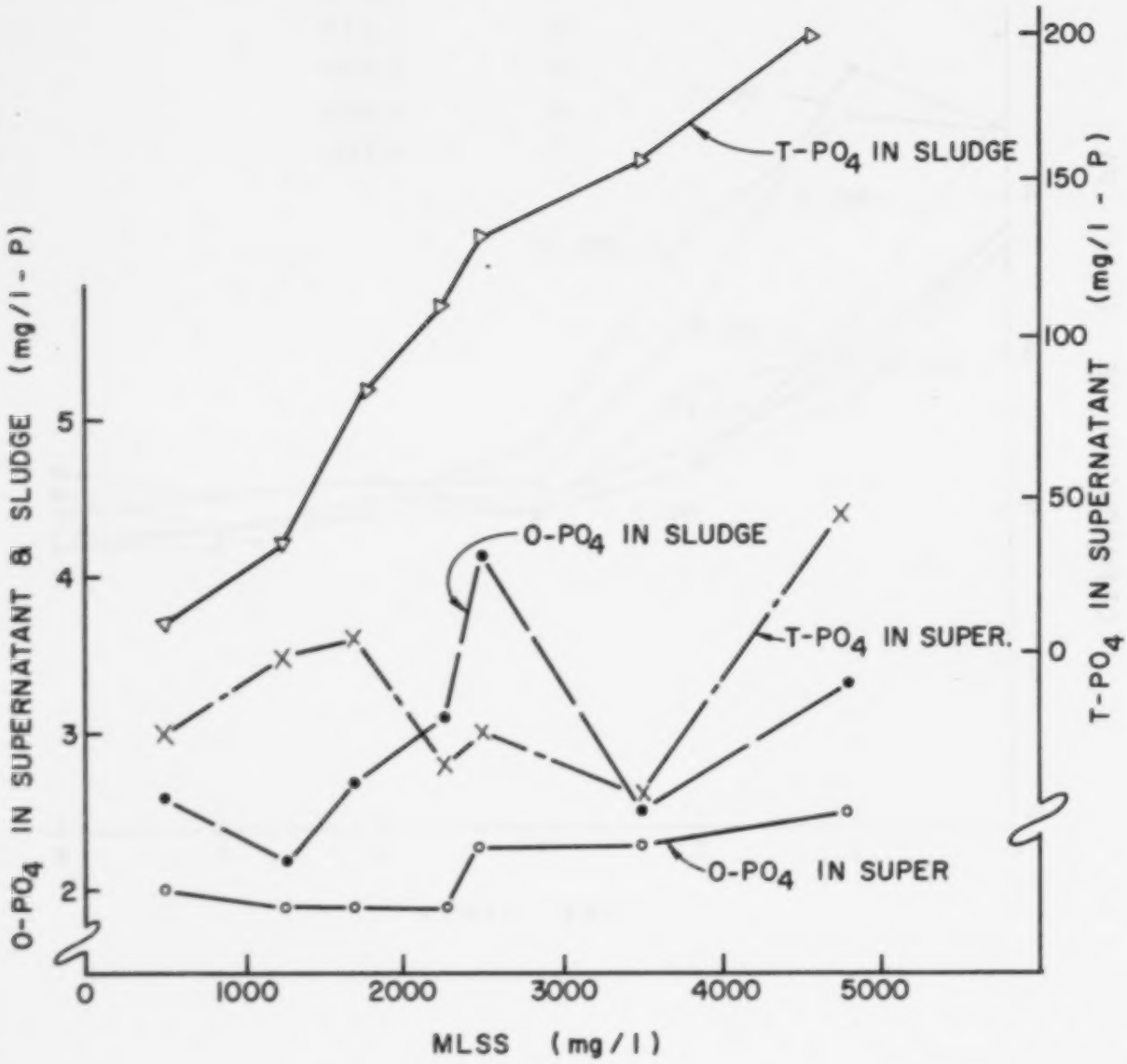

FIGURE 8 – MLSS VARIATION - SUPERATANT & SLUDGE PHOSPHATE

of a BOD supplement (Metrecal*) to 10 liters of primary effluent. The jug components and test results are shown in Tables 4 and 5.

Mixed liquor from the head of Aeration Tank B-2 was used in Jug No. 6 for comparison with the synthetic mixed liquor of the other jugs.

Table 4

BOD Load Variation - Components

Component	Jug No. 1	2	3	4	5	6	Analysis $O\text{-}PO_4$ (mg/l-P)
PE (liters)*	5.0	10.0	10.0	10.0	10.0	--	6.0
Conc. RS (liters)	2.5	2.5	2.5	2.5	2.5	--	6.5
FE (liters)	7.5	2.5	2.5	2.5	2.5	--	4.7
ML (liters)	--	--	--	--	--	15	--
Metrecal (ml)**	--	--	1.3	3.5	7.8	--	--
Analysis (mg/l)							
TSS	2,755	2,675	2,825	2,675	2,890	1,195	
Est. Substrate BOD (mg/l)	75	150	190	250	375	150	
Est. Substrate BOD load (%)	50	100	125	165	250	--	

*For analyses of components, see Table 1.
**Metrecal contains 1.1 mg/ml $O\text{-}PO_4$ as P and 290 mg/ml BOD.

Table 5

BOD Load Variation - Results
$O\text{-}PO_4$ (mg/l-P)

Aeration Time (Hrs)	Jug No. 1	2	3	4	5	6
0 (11:00 a.m.)	4.8	6.1	6.3	6.6	6.6	6.1
1	3.9	4.4	5.1	6.1	5.4	5.1
2	3.4	3.7	4.0	4.3	3.7	4.5
3	3.4	3.4	3.4	3.3	3.0	4.0
4	3.4	3.3	3.4	3.2	2.9	3.9
5	3.4	3.3	3.4	3.3	2.8	3.6
% Removal	29	46	46	50	58	41

*See page 43.

Orthophosphate removal with respect to aeration time is shown in Figure 9. As in the suspended solids variation study, the maximum removal took place in the first 3 hours. Initial orthophosphate values for Jugs Nos. 1 through 5 agree with theoretical values based on volumes of jug components within 10 percent.

Soluble nonvolatile organic carbon (SNVOC) determinations were made on jug mixed liquor filtrate at the start of the experiment. These data are plotted against estimated substrate BOD to show the increase in carbon load from Jugs Nos. 1 through 5 (Figure 10).

Percent orthophosphate removal with respect to estimated substrate BOD concentration was plotted in Figure 10. Both magnitude and percent orthophosphate removal increased as the substrate BOD concentration increased. The plant mixed liquor (Jug No. 6) removed almost as much phosphate as its synthetic BOD equivalent (Jug No. 2).

An additional experiment was performed on June 15, 1967, for verification of BOD influence. Two jugs (Nos. 2 and 5) were prepared using concentrated return sludge and primary effluent. Fifteen milliliters of Metrecal were added to Jug No. 5 to increase the substrate BOD to about 375 percent of that in the control Jug No. 2. The jug components and analytical results are shown in Tables 6 and 7, respectively. The control jug removed 23.0 percent of the soluble phosphate while Jug No. 5 removed 49 percent. Mixed liquor from the head of Aeration Tank B-2 (Jug No. 1 in Table 7) removed 11 percent during this aeration period. Phosphate release was noted in the heavily-loaded BOD jug during the first hour of aeration. San Antonio aeration tanks at high organic and hydraulic loading had a similar pattern of release.[1]

These experiments lend further support to the conclusion that orthophosphate removal increases with increasing substrate BOD concentration.

Phosphate Variation

A set of four jugs was prepared on June 15, 1967 to determine the effect of soluble phosphorus concentration on orthophosphate removal. Jug components and analytical results are shown in Tables 6 and 7.

Jug No. 1 contained mixed liquor from the head of Aeration Tank B-2 and served as the plant reference. Jugs Nos. 3 and 4 were set up to contain one-half and twice the initial phosphate concentration of Jug No. 2, respectively. Jug No. 2 served as a control.

Since phosphate removal was found to increase with increasing substrate BOD, this experiment was set up to simulate conditions which would result from bypassing a portion of the primary clarifiers. The amount of BOD substrate was increased by using larger quantities of primary effluent. Simulation of raw sewage BOD concentration was not selected since direct dosing of raw sewage to the aeration tanks would result

JUG NO.	MLSS (mg/l)
1	2,755
2	2,675
3	2,825
4	2,675
5	2,890
6	1,195

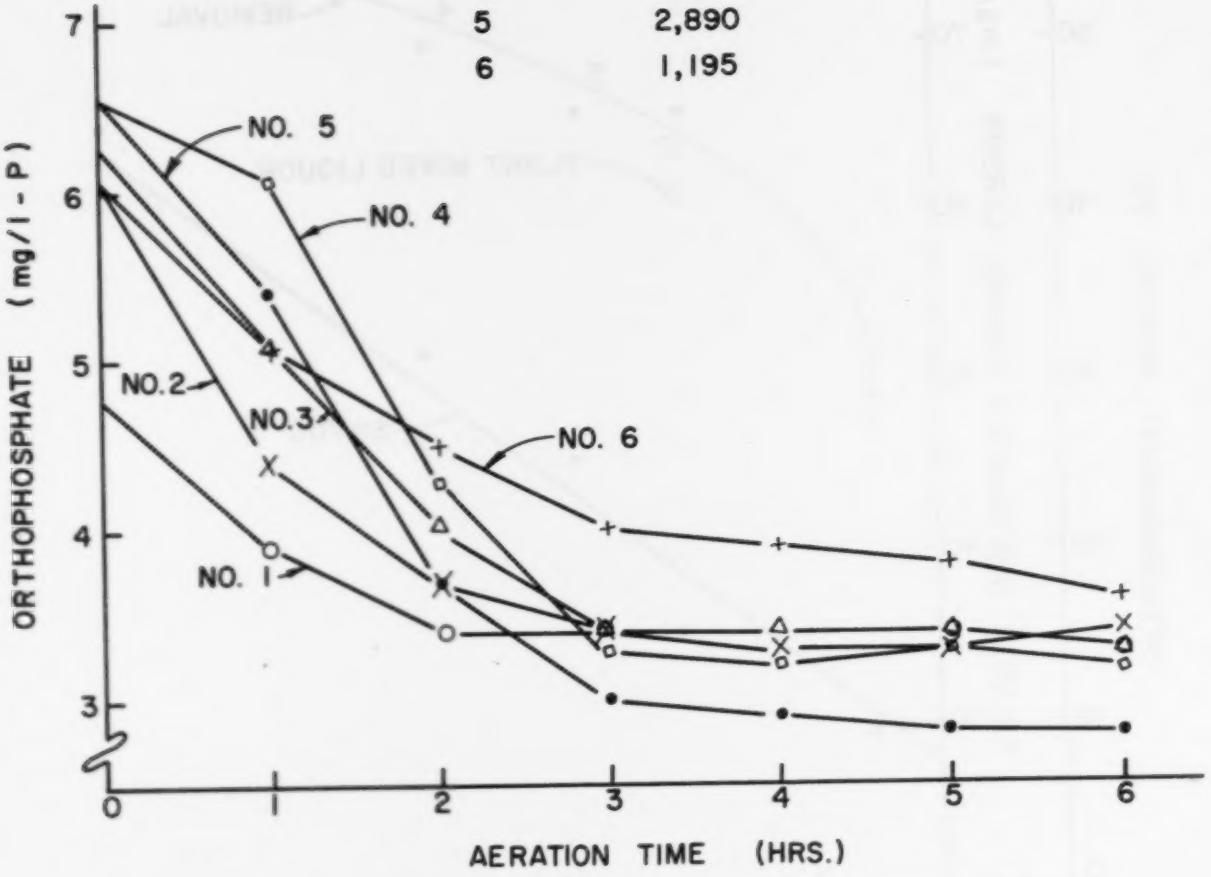

FIGURE 9 – BOD VARIATION – PHOSPHATE

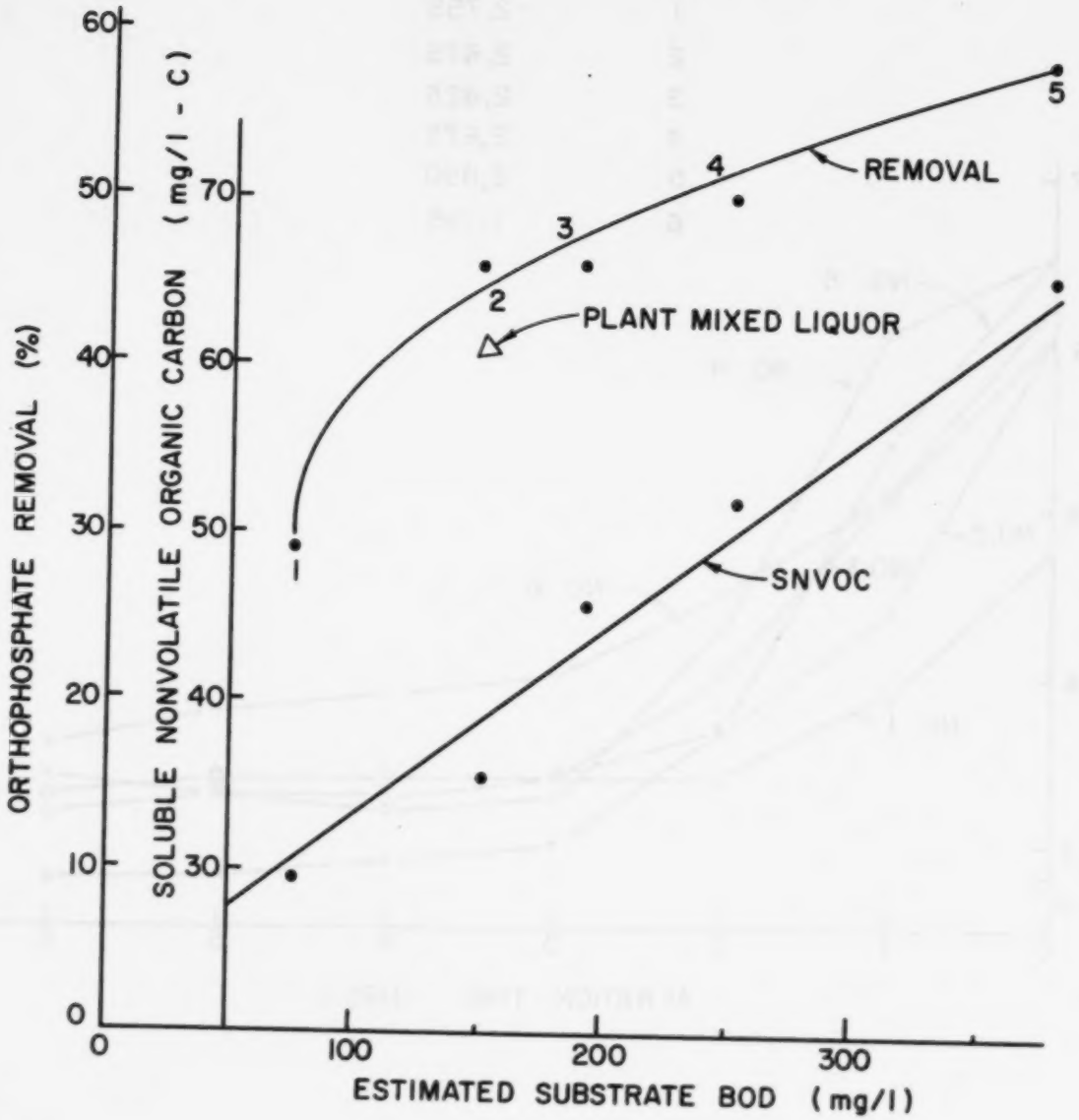

FIGURE 10 - BOD VARIATIONS - PHOSPHATE REMOVAL & SNVOC

in grease and scum accumulation in the final clarifiers which are not equipped with skimming facilities.

Table 6

Phosphate Variation - Components

Components	Jug No. 1	2	3	4	5*
PE (liters)	-	12.5	6.3	12.5	12.5
Conc. RS (liters)	-	2.5	2.5	2.5	2.5
FE (liters)	-	-	-	-	-
ML (liters)	15	-	-	-	-
Metrecal (ml)	-	-	3.0	-	15.0
K_2HPO_4 (mg/l-P)	-	-	-	6.0	-
City Water (liters)	-	-	6.2	-	-
TSS (mg/l)	1,600	2,765	2,940	3,095	3,040

*BOD Variation Study

Note: For analyses of components, see Table 1.

Jug No. 3 containing about half of the normal phosphate concentration removed 55 percent of the soluble phosphate in the initial three hours of the study and then exhibited phosphate release. After 6 hours' aeration, the overall removal was 28 percent. Similar results were observed in Jugs Nos. 2 and 4. Jug No. 2 removed 32 percent after 3 hours' aeration, but only 23 percent in 6 hours. Jug No. 4 removed 27 percent in 3 hours and 23 percent after 6 hours' aeration. Jug No. 1, containing plant mixed liquor, removed 11 percent of the soluble phosphate during the 6-hour period. Figure 11 is a plot of phosphate removal versus aeration time.

Table 7 reveals that although percent removal is not affected significantly by initial phosphate concentration in the range 6.5 to 12.4 mg/l-P, there is a slight increase in the weight removed with increasing initial phosphate concentration. In order of increasing phosphate concentration, Jugs Nos. 3, 2, and 4 removed 1.1, 1.5, and 2.9 mg/l-P, respectively, after 6 hours' aeration.

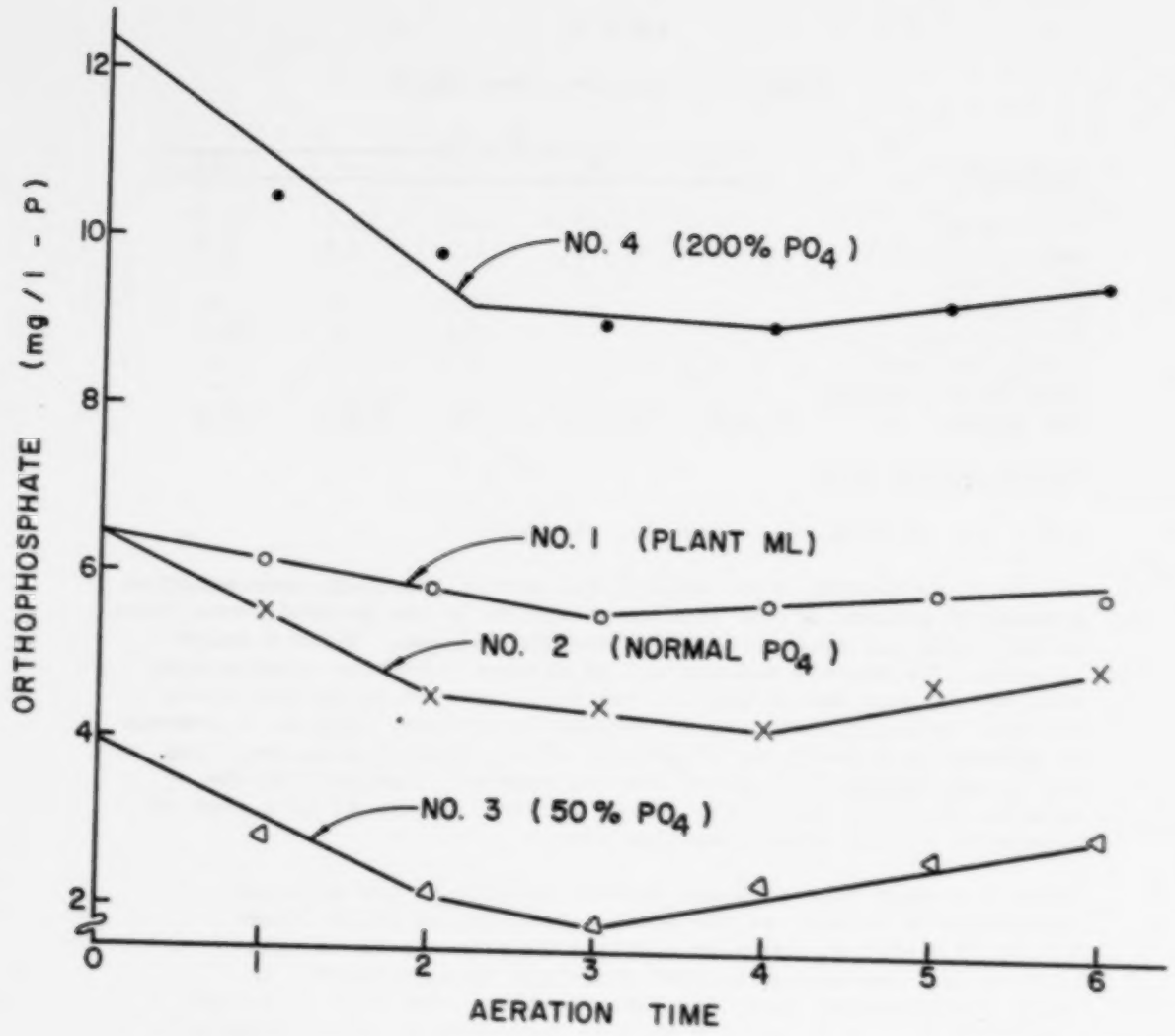

FIGURE II - PHOSPHATE VARIATIONS - PHOSPHATE

Table 7

Phosphate Variation - Results
$O\text{-}PO_4$ (mg/l-P)

Aeration Time (Hrs)	Jug No. 1	2	3	4	5*
0 (10:30 a.m.)	6.5	6.5	4.0	12.4	7.7
1	6.0	5.5	2.8	10.5	8.8
2	5.8	4.5	2.2	9.8	7.5
3	5.5	4.4	1.8	9.0	6.2
4	5.6	4.2	2.3	9.0	5.5
5	5.8	4.8	2.7	9.4	4.2
6	5.8	5.0	2.9	9.5	3.9
% Removal	11	23	28	23	49

* BOD Variation Study

Chemical Variation

Five jugs were set up on June 16, 1967, to determine the effect of chemical addition and variation in hardness on phosphate removal. Jugs were prepared using 13 liters of primary effluent rather than 10 liters to increase the BOD substrate. The MLSS concentration varied from 2,900 to 3,100 mg/l.

Two jugs were set up to determine the effect of ferrous iron and aluminum salts on phosphate removal. Orthophosphate concentration was determined on primary effluent. Then, Jugs Nos. 2 and 3 were dosed with 25 mg/l of ferrous and aluminum ion, respectively. After chemical addition and thorough mixing, the soluble orthophosphate concentration was immediately determined. Return sludge was then added to these jugs to produce mixed liquor, and orthophosphate was again determined. The jugs were aerated and monitored for 6 hours. Table 8 lists the jug components.

Two jugs were set up to determine the effect of variation in hardness on phosphate removal. The primary effluent used for jug makeup contained 420 mg/l total hardness as $CaCO_3$. Jug No. 4 was set up to have a 200 mg/l hardness by dilution with deionized primary effluent. Jug No. 5 was dosed with calcium chloride to simulate a hardness of 500 mg/l.

Jug No. 6 served as a control for both the chemical addition and hardness variation studies. Jug No. 1 contained acclimated sludge and is listed under "Acclimation Studies."

Table 8

Chemical Variation - Components

Components	Jug No. 2	3	4	5	6
PE (liters)	13.0	13.0	13.0*	13.0	13.0
Conc. RS (liters)	2.0	2.0	2.0	2.0	2.0
$FeSO_4$ (mg/l-Fe)	25.0	-	-	-	-
$Al_2(SO_4)_3$ (mg/l-Al)	-	25.0	-	-	-
$CaCl_2$ (mg/l-Ca)	-	-	-	26.0	-
Air (ft^3/m)	17.5	17.5	17.5	17.5	17.5
TSS (mg/l)	3,040	3,060	2,860	2,980	3,120

*Consisted of 6.5 liters of PE + 6.5 liters of PE after mixed bed deionizer treatment.

Note: For analyses of components, see Table 1.

The results are shown in Table 9 and Figure 12. The addition of iron and aluminum salts immediately reduced the orthophosphate concentration by 79 and 95 percent, respectively. The addition of return sludge to provide a MLSS concentration of about 3,000 mg/l increased the initial orthophosphate concentrations to 1.7 and 0.4 mg/l in Jugs Nos. 2 and 3, respectively. The lower concentration of orthophosphate in Jug No. 3 was attributed to precipitation of the phosphate by residual aluminum ion prior to mixed liquor sampling. After 6 hours' aeration, the orthophosphate decreased from 1.7 to 0.9 mg/l in the mixed liquor containing iron. The jug containing aluminum reduced the concentration from 0.4 to 0.2 mg/l during the same period. The increase in orthophosphate concentrations which occurred during the last three hours of aeration was greater in the jug containing iron.

Jug No. 4 containing 200 mg/l hardness showed a 25 percent removal of soluble phosphate, while Jug No. 5, containing 500 mg/l hardness, removed 33 percent soluble phosphate. The control jug containing 420 mg/l hardness removed 31 percent. Release occurred in each of the jugs although not to the extent noticed in the suspended solids and BOD studies.

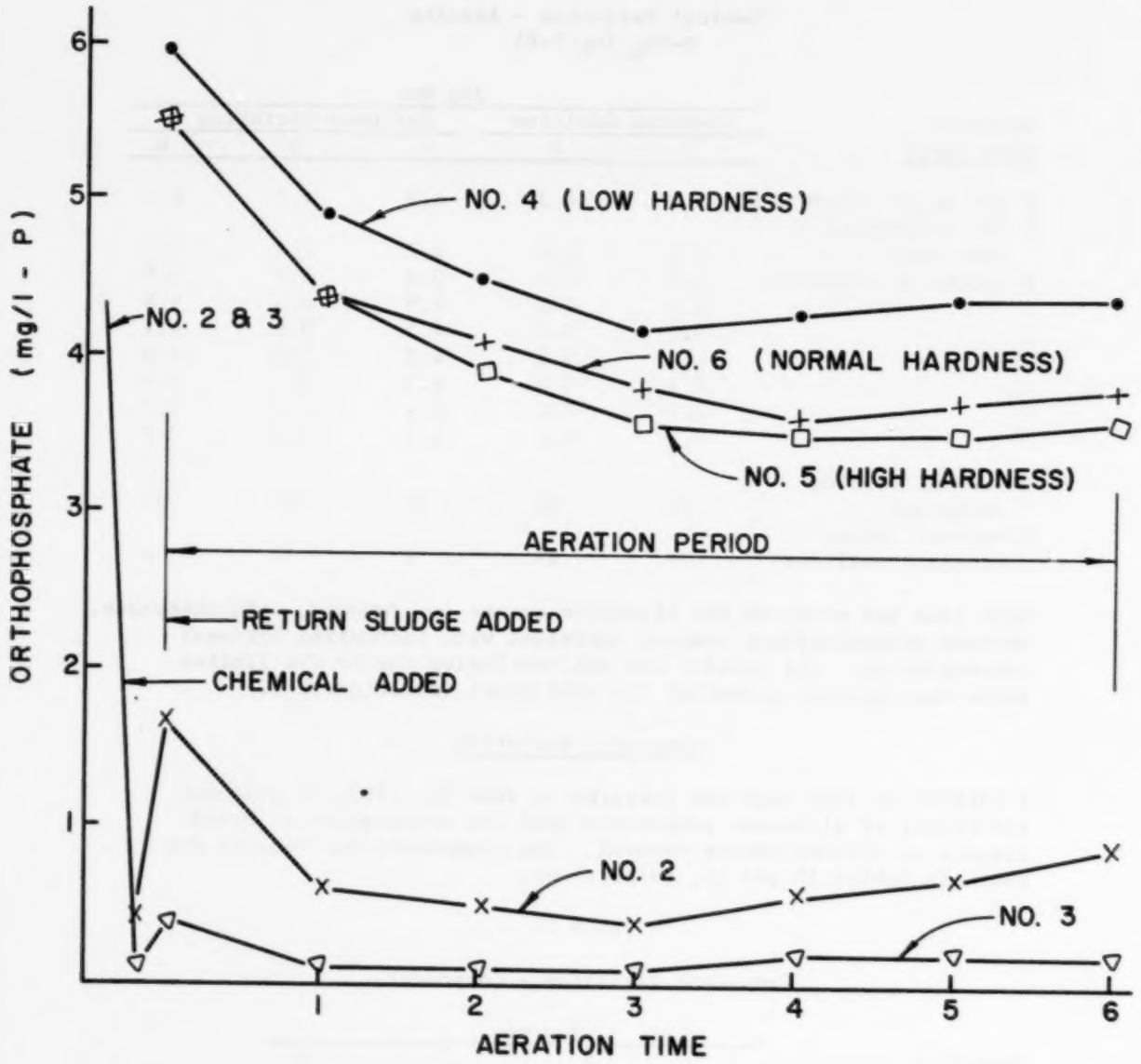

FIGURE 12 - CHEMICAL ADDITION - PHOSPHATE

Table 9

Chemical Variation - Results
$O\text{-}PO_4$ (mg/l-P)

Aeration Time (Hrs)	Jug No.				
	Chemical Addition		Hardness Variation		
	2	3	4	5	6
0 (PE only) (11:00 a.m.)	4.3	4.3	4.3	4.3	4.3
0 (PE + chemical addition)	0.2	0.1	4.7	4.4	4.7
0 (after RS addition)	1.7	0.4	5.9	5.5	5.5
1	0.6	0.1	4.9	4.4	4.4
2	0.5	0.1	4.5	3.9	4.1
3	0.4	0.1	4.2	3.6	3.8
4	0.6	0.2	4.3	3.5	3.6
5	0.7	0.2	4.4	3.5	3.7
6	0.9	0.2	4.4	3.6	3.8
% Removal (during aeration)	47	50	25	33	31
% Removal (after chemical addition)	79	95	-	-	-

Both iron and aluminum are effective agents for removing orthophosphate. Percent orthophosphate removal increased with increasing hardness concentration. The results are not conclusive due to the limited tests but indicate potential for additional investigations.

Component Variation

A battery of four jugs was prepared on June 21, 1967, to evaluate the effect of different components used for preparation of mixed liquors on orthophosphate removal. Jug components and results are shown in Tables 10 and 11, respectively.

Table 10

Component Variation - Components

Component (liters)	Jug No.			
	1	2	3	4
Raw	-	-	10.0	-
PE	-	10.0	-	10.0
Conc. RS*	-	6.0	6.0	-
ML	15	-	-	-
Conc. ML**	-	-	-	5.0
TSS (mg/l)	1,530	2,650	2,620	2,800

* Return sludge concentrated 2:1 by settling.
**Mixed liquor from head of Aeration Tank B-2 concentrated 6:1 with cationic polymer.

Jug No. 1 (plant mixed liquor) was used as the control and removed 42 percent of the initial orthophosphate. About the same percent removal was observed in Jug No. 2 using PE as the BOD source. In Jug No. 3, raw sewage was used instead of primary effluent and resulted in 53 percent orthophosphate removal. Jug No. 4 containing concentrated mixed liquor plus PE exhibited 72 percent removal of soluble orthophosphate. The most notable difference between these jugs was the soluble nonvolatile organic carbon content. Phosphate removal increased with increasing initial organic carbon concentration, thus substantiating the results of the BOD variation experiment.

Table 11

Component Variation - Results

Aeration Time (Hrs)	SNVOC (mg/l) Jug No. 2	3	4	O-PO_4 (mg/l-P) Jug No. 1	2	3	4
0 (11:30 a.m.)	59.0	81.2	116	6.4	6.0	5.7	6.3
1	-	-	-	5.1	4.5	4.1	5.0
2	-	-	-	4.4	4.0	3.3	3.5
3	31.5	35.5	41.0	4.4	4.0	3.2	2.9
4	-	-	-	4.1	3.7	2.8	2.2
5	22.7	27.5	28.7	3.7	3.6	2.7	1.8
% Removal	61	66	75	42	40	53	72

Figure 13 displays orthophosphate concentration versus aeration time for Jugs Nos. 1 through 4. None of the jugs exhibited release in contrast to data from previous studies.

The soluble nonvolatile organic carbon and orthophosphate concentrations in Table 11 indicate the higher the SNVOC initial concentration (organic load) the higher the phosphate removal. The rates of SNVOC and phosphate reduction are similar; both decrease more rapidly during the initial 3 hours of aeration.

Acclimation Study

At 6:00 p.m. on June 14, a study was started to acclimate the plant sludge to orthophosphate removal under controlled conditions. The contents of Jug No. 3 of the BOD variation study was allowed to settle for one hour, after which 10 liters of supernatant were decanted and replaced with 10 liters of primary effluent. Metrecal solution was continuously fed overnight to simulate a high unit BOD load. Supplemental phosphate was added, and the jug was aerated at 17.5 liters per minute.

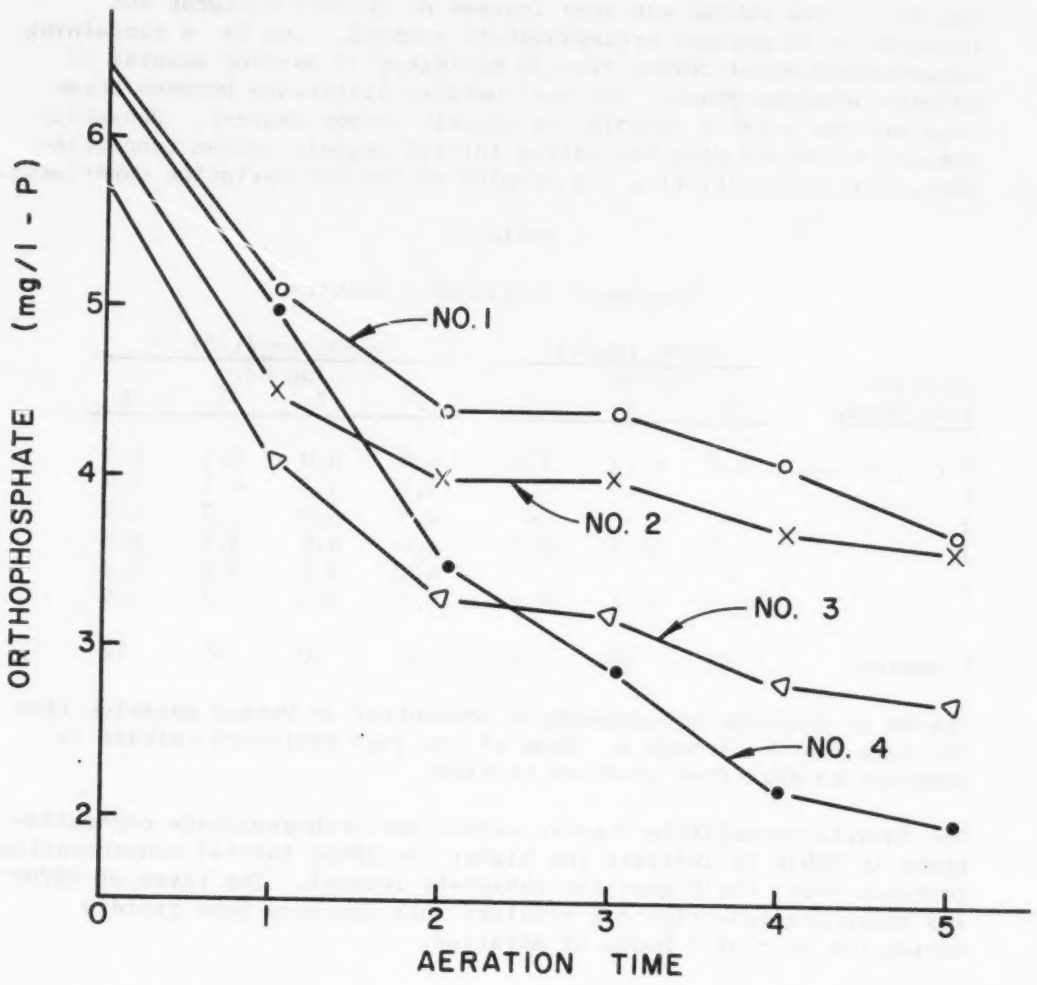

FIGURE 13 - COMPONENT VARIATION - PHOSPHATE

At 9:30 a.m. on June 15, 1967, the contents were again settled for 45 minutes, the supernatant decanted, and 7.5 liters of primary effluent was added. Three milliliters of Metrecal were added to supplement the BOD load to typical plant conditions. Aeration was started and the acclimated and control jugs were monitored from 10:30 a.m. to 4:30 p.m. (Table 12). At 1:00 p.m. (2.5 hours), an additional 5 milliliters of Metrecal were added to increase BOD loading because analysis showed a low carbon content. The jug was fed 421 milliliters of Metrecal-phosphate solution overnight with an aeration rate of 17.5 liters per minute. The overall orthophosphate load during the 16-hour overnight aeration periods was about 25 mg/l as phosphorus (including the initial jug concentration).

At 9:00 a.m. on June 16, 1967, aeration was again stopped and the contents allowed to settle. The supernatant was decanted and replaced with 8.5 liters of primary effluent and 2.5 milliliters of Metrecal. Aeration of the mixed liquor was initiated at 11:00 a.m. and continued for 6 hours.

The analytical results for the acclimation and control jugs are shown in Table 12. The acclimated jugs removed 78 percent of the phosphate during both 6-hour aeration periods, whereas the control jugs removed 23 and 31 percent.

The results from these experiments offer evidence that Indianapolis sludge can be acclimated to high levels of soluble orthophosphate removal.

Table 12

Acclimation-Control Comparison
June 15-16, 1967
$O\text{-}PO_4$ as P (mg/l)

Aeration Time (Hrs)	6/15/67 Acclimated Jug	6/15/67 Control Jug*	6/16/67 Acclimated Jug	6/16/67 Control Jug**
0	6.9	6.5	4.9	5.5
1	6.1	5.5	4.5	4.4
2	3.7	4.5	4.0	4.1
3	3.2	4.4	3.3	3.8
4	2.3	4.2	2.4	3.6
5	1.4	4.8	1.3	3.7
6	1.5	5.0	1.1	3.8
% Removal	78	23	78	31
MLSS (mg/l)	3,230	2,765	3,810	3,120

* Components: Jug No. 2, Table 6. Note: Aeration rate = 17.5 liters per minute.
**Components: Jug No. 6, Table 8.

Sewage Characterization

A related purpose of the amenability analytical program was to characterize samples from the various unit processes of activated sludge plants with regard to selected chemical parameters. Additional samples from an aeration jug study were included in the characterization scheme. Such samples were taken from a jug study whose constituents and operation resulted in maximum phosphate removal. Primarily, the intention was to search for trends or correlatable functions within or between various chemical parameters which would be useful in defining the phosphate removal process. Frequently, phosphate removal realized from jug aeration was higher than that occurring in the aeration tanks. During such instances, the probability of identifying the significant differences in chemical composition was enhanced.

The samples were analyzed with and without solids to differentiate between the quantity of each chemical parameter associated with the solids from those associated with the liquid. Separation was accomplished by first decanting, then subjecting the resulting supernatant to further solids removal using a Sharples Ultra Centrifuge.*

The significance of the results will not be discussed in this report since the basic purpose was for comparison with similar data from other studies. The data are presented and compared under separate cover.[5]

Microbiological Studies

This study was divided into two sections. The first section was total plate counts of the various unit processes and aeration jug samples. The second section included the selection of predominant colonies, transfer of these colonies to agar slants, and shipment to the Ada laboratory for identification.

There is no apparent correlation between plate counts, phosphate removal capabilities, and total or volatile suspended solids content of the mixed liquor. If such a relationship does exist, it was not detected by the methods employed.

A separate report[6] presents the data and discusses the microbiological studies conducted during the amenability investigations.

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*See page 43.

SUMMARY

Studies conducted on the activated sludge facilities at the Southwest Sewage Treatment Plant, Indianapolis, Indiana, from June 12 to 21, 1967, indicate orthophosphate removal averaging 20 percent through the aeration tank, but only 10 percent from primary to final effluent.

The diurnal variation of BOD concentration in the raw sewage entering the plant is typical; however, arrival of peak concentrations are delayed until the early afternoon period due to the 2-hour flow time from the main plant to the Southwest Plant.

The aeration tanks are four-pass with a length to width ratio of 25:1. Dye tracer studies conducted during conventional flow-through conditions show that the tank effluent has a dispersion index (t_{90}/t_{10}) of 2.25 and a modal detention time equal to 78 percent of the displacement time. All of the mixed liquor flow receives more than two hours of aeration, and only 3 percent of the flow receives less than 3 hours' aeration.

Dye tracer studies conducted during step-feeding conditions (equal splitting of primary effluent between quarter and half points) show that the detention time is reduced compared to conventional flow-through operation. Eight percent of the mixed liquor flow receives less than 2 hours of aeration and 34 percent less than 3 hours.

Dye tracer studies of the circular final clarifiers indicate that the overflow has a modal detention time of 1 hour, and half of the return sludge flow consists of short-circuited mixed liquor.

The plant MLSS concentration ranged from 1,625 to 2,343 mg/l, and the return sludge ranged from 2,710 to 4,600 mg/l of TSS. The return sludge is typically 55 percent of the primary effluent. The primary effluent flow is usually controlled from the main plant at between 25 and 28 mgd. The diurnal flow variation does not normally exceed 10 percent of the average daily inflow. About 500,000 gallon per day of activated sludge is wasted.

The amount of air supplied ranges from 1.7 to 2.7 cubic feet per gallon of waste treated, which resulted in a dissolved oxygen concentration of 2.5 to 4 mg/l in the aeration tank effluent. The dissolved oxygen in the final clarifiers averaged 0.5 to 0.9 mg/l. Sludge blanket depths in the final clarifiers varied from 12 inches at the side wall to a range of 2 to 4 feet at the center. Blanket depth cannot be reduced with the present sludge scraper performance.

Plant monitoring during the study period shows that phosphate concentrations (mg/l-P) in the waste streams were as follows:

Source	Ortho		Total		Avg. Ortho/Total
	Min.	Max.	Min.	Max.	
Raw	4.8	5.5	9.3	10.9	0.51
PE	4.3	7.4	4.6	8.1	0.83
FE	4.4	7.0	2.7	10.0	0.92
RS	3.0	9.1	58.0	147.5	0.06

Daily orthophosphate and BOD loadings in the aeration tanks ranged from 2.3 to 4.0 pounds phosphorus per day per 100 pounds MLSS and from 9 to 16 pounds BOD per day per 100 pounds MLSS, respectively.

Pilot studies were conducted in aerated jugs to determine the effect on orthophosphate removal caused by (1) variation in MLSS, BOD, orthophosphate, and hardness concentration, (2) addition of ferrous iron and trivalent aluminum, and (3) sludge acclimation.

The MLSS concentration and phosphate removal were not highly correlated as the MLSS was increased from 453 to 4,760 mg/l; the removal varied from 47 to 54 percent. Excluding this MLSS study, the mixed liquor in the jugs was synthesized from 2,600 to 3,100 mg/l suspended solids. As the substrate BOD was increased from 50 to 250 percent of the normal primary effluent, the removal increased from 29 to 58 percent. Variation in orthophosphate loading from 50 to 200 percent of the primary effluent concentration did not significantly effect phosphate removal. Removal increased from 25 to 33 percent as hardness concentration was increased from 200 to 500 mg/l.

Addition of 25 mg/l iron or aluminum to primary effluent resulted in 79 percent removal with iron and 95 percent with aluminum.

After acclimating for a period of 16 to 40 hours, the return sludge removed 78 percent of the orthophosphate in the acclimated jugs whereas 23 and 31 percent were removed in the control jugs.

SUMMARY

Studies conducted on the activated sludge facilities at the Southwest Sewage Treatment Plant, Indianapolis, Indiana, from June 12 to 21, 1967, indicate orthophosphate removal averaging 20 percent through the aeration tank, but only 10 percent from primary to final effluent.

The diurnal variation of BOD concentration in the raw sewage entering the plant is typical; however, arrival of peak concentrations are delayed until the early afternoon period due to the 2-hour flow time from the main plant to the Southwest Plant.

The aeration tanks are four-pass with a length to width ratio of 25:1. Dye tracer studies conducted during conventional flow-through conditions show that the tank effluent has a dispersion index (t_{90}/t_{10}) of 2.25 and a modal detention time equal to 78 percent of the displacement time. All of the mixed liquor flow receives more than two hours of aeration, and only 3 percent of the flow receives less than 3 hours' aeration.

Dye tracer studies conducted during step-feeding conditions (equal splitting of primary effluent between quarter and half points) show that the detention time is reduced compared to conventional flow-through operation. Eight percent of the mixed liquor flow receives less than 2 hours of aeration and 34 percent less than 3 hours.

Dye tracer studies of the circular final clarifiers indicate that the overflow has a modal detention time of 1 hour, and half of the return sludge flow consists of short-circuited mixed liquor.

The plant MLSS concentration ranged from 1,625 to 2,343 mg/l, and the return sludge ranged from 2,710 to 4,600 mg/l of TSS. The return sludge is typically 55 percent of the primary effluent. The primary effluent flow is usually controlled from the main plant at between 25 and 28 mgd. The diurnal flow variation does not normally exceed 10 percent of the average daily inflow. About 500,000 gallon per day of activated sludge is wasted.

The amount of air supplied ranges from 1.7 to 2.7 cubic feet per gallon of waste treated, which resulted in a dissolved oxygen concentration of 2.5 to 4 mg/l in the aeration tank effluent. The dissolved oxygen in the final clarifiers averaged 0.5 to 0.9 mg/l. Sludge blanket depths in the final clarifiers varied from 12 inches at the side wall to a range of 2 to 4 feet at the center. Blanket depth cannot be reduced with the present sludge scraper performance.

Plant monitoring during the study period shows that phosphate concentrations (mg/l-P) in the waste streams were as follows:

Source	Ortho		Total		Avg. Ortho/Total
	Min.	Max.	Min.	Max.	
Raw	4.8	5.5	9.3	10.9	0.51
PE	4.3	7.4	4.6	8.1	0.83
FE	4.4	7.0	2.7	10.0	0.92
RS	3.0	9.1	58.0	147.5	0.06

Daily orthophosphate and BOD loadings in the aeration tanks ranged from 2.3 to 4.0 pounds phosphorus per day per 100 pounds MLSS and from 9 to 16 pounds BOD per day per 100 pounds MLSS, respectively.

Pilot studies were conducted in aerated jugs to determine the effect on orthophosphate removal caused by (1) variation in MLSS, BOD, orthophosphate, and hardness concentration, (2) addition of ferrous iron and trivalent aluminum, and (3) sludge acclimation.

The MLSS concentration and phosphate removal were not highly correlated as the MLSS was increased from 453 to 4,760 mg/l; the removal varied from 47 to 54 percent. Excluding this MLSS study, the mixed liquor in the jugs was synthesized from 2,600 to 3,100 mg/l suspended solids. As the substrate BOD was increased from 50 to 250 percent of the normal primary effluent, the removal increased from 29 to 58 percent. Variation in orthophosphate loading from 50 to 200 percent of the primary effluent concentration did not significantly effect phosphate removal. Removal increased from 25 to 33 percent as hardness concentration was increased from 200 to 500 mg/l.

Addition of 25 mg/l iron or aluminum to primary effluent resulted in 79 percent removal with iron and 95 percent with aluminum.

After acclimating for a period of 16 to 40 hours, the return sludge removed 78 percent of the orthophosphate in the acclimated jugs whereas 23 and 31 percent were removed in the control jugs.

CONCLUSIONS

Plant Studies

1. Limited plant studies indicate that the activated sludge facilities at the Southwest Indianapolis Sewage Treatment Plant are not removing high levels of orthophosphate.

2. The BOD and orthophosphate concentrations in the primary effluent are about 50 to 60 percent and 60 to 70 percent, respectively, of that prevalent in the San Antonio[2] wastes.

3. When step feeding is not being practiced, the aeration tanks exhibit less longitudinal mixing and better plug-flow characteristics than those of the San Antonio Rilling Plant.

4. Sufficient aeration time is provided for high orthophosphate removal in both the conventionally-fed and step-fed tanks.

5. The concentrations of the dissolved oxygen present in the aeration tanks are sufficient to allow phosphate removal.

6. Conditions found in the final clarifiers indicate an environment which would be conducive to high levels of phosphate release due to low dissolved oxygen levels and excessive sludge detention time. The plant cannot be operated for optimum phosphate removal until rapid sludge removal is provided.

Jug Studies

1. Orthophosphate removal does not vary significantly nor correlate with variation in MLSS concentration.

2. At constant MLSS concentration, orthophosphate removal increases as the substrate BOD concentration increases.

3. At constant MLSS and BOD concentrations, percent orthophosphate removal does not change significantly with variation in initial orthophosphate concentration.

4. At constant MLSS, BOD, and orthophosphate concentrations, orthophosphate removal increases as the hardness increases.

5. Ferrous iron and aluminum salts are effective removal agents of soluble orthophosphate. Aluminum was more effective than iron.

6. Bacterial plate count does not correlate with soluble orthophosphate removal.

7. The waste and sludge are amenable to phosphate removal. After a period of acclimation, the sludge is capable of removing 2.5 to 3 times as much orthophosphate as the unacclimated sludge.

RECOMMENDATIONS

1. It is recommended that the Southwest Plant be considered as a site for demonstrating phosphate removal by activated sludge. Although amenability of the sludge to high levels of phosphate removal was conclusive only after acclimation, the following advantages justify the above recommendation: (1) presence of a controlled plant inflow exhibiting only minimum diurnal flow variation; (2) use of a relatively new and reliable physical plant; (3) flexibility of plant operation; (4) minimum aeration tank short circuiting; (5) absence of return flows since primary and waste activated sludges are lagooned; and (6) interest in nutrient removal exhibited by plant personnel.

2. The following changes may be necessary to optimize operating parameters considered essential to obtain high levels of soluble phosphate removal:

a. Increase the primary effluent BOD concentration by removing one or two of the primary clarifiers from service and/or

b. Waste a larger quantity of return sludge to increase the unit BOD loading (lb./day/lb. MLSS) and decrease the sludge age.

c. Maintain a readily-settleable mixed liquor and returning the sludge rapidly to minimize sludge detention in the final clarifiers. This may require replacement or modification of the sludge removal mechanism.

d. Adjust aeration rates to maintain a residual dissolved oxygen concentration in the final clarifiers sufficient to minimize release of phosphate into the effluent.

APPENDIXES

Appendix I

Analytical Procedures
by
B. L. DePrater

Sample Preparation

Samples collected for analyses in the field were processed as outlined in the respective analytical test procedures.

Samples returned to the Robert S. Kerr Water Research Center are referred to as whole, centrate, whole fixed, and centrate fixed.

The following table lists the treatment each type received prior to shipment to Ada.

Sample	Treatment
1. Whole	Shipped as is with no treatment.
2. Whole Fixed	Shipped as is plus 1 ml conc. sulfuric acid per liter of sample.
3. Centrate	The sample was passed through a Sharples* motor driven laboratory model continuous centrifuge, equipped with a clarifier bowl driven at 23,000 rpm. The sample was delivered to the centrifuge by a peristaltic pump at a feed rate of 150 ml/min. The bowl was cleaned and rinsed with distilled water after each sample.
4. Centrate Fixed	The centrate sample plus 1 ml/l conc. sulfuric acid.

All samples were shipped in either 250 ml plastic bottles or 1,000 ml cubetainers.**

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*See page 43.

**Hedwin Corporation, 1600 Roland Heights Avenue, Baltimore, Maryland 21211.

Chemical Tests

1. Orthophosphate

In the field, initial samples for orthophosphate were filtered immediately using Schleicher and Schuell* No. 588 paper. Subsequent analysis by the stannous chloride procedure in Standard Methods[4] included the use of a B&L Spectronic 20* at 690 mμ.

A continuous automatic sampling device, built specifically to support jug-study phosphate analyses, supplied whole samples to a Technicon AutoAnalyzer platformed according to the method by Gales and Julian.[7] The manifold and reagents were modified, however, to more closely approximate Standard Methods.[4] The arrangement, in order of sequence, was as follows:

a. A six-port peristaltic pump circulating jug mixed liquor continuously.

b. An open-shut solenoid valve system selectively sampling the flow from a T-connection in each circulating jug line.

c. A stepping relay alternately activating one of six jug sample solenoids or the solenoid to a distilled wash water supply.

d. A master timer regulating the stepping relay at two-minute intervals.

e. A Technicon* proportioning pump providing the flow of samples and distilled water to a Technicon continuous filter. This pump also diluted filtered samples with distilled water in the ratio of 1:40, respectively.

Whole plant samples were run on the Technicon AutoAnalyzer using a Technicon Sampler II and a continuous filter with samples reaching the filter within thirty minutes. No significant orthophosphate bleedback occurred in unfiltered samples during this period.

2. Total Phosphate

Analyses were conducted on fixed whole samples at the Ada laboratory within 15 days of sample collection. Initially whole

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*See page 43.

samples were blended for three to five minutes in a Waring Blendor* and then analyzed by the persulfate procedure of Gales and Julian.[7] The procedure was modified to more closely approximate the Standard Methods[4] procedure for orthophosphate in that the samples were neutralized after digestion. Also the manifold design and reagents for the AutoAnalyzer were adjusted to deliver approximately the amount of reagents per sample outlined by Standard Methods.[4]

3. Total Carbon and Total Nonvolatile Organic Carbon

Whole samples were run in the field using the methods of Van Hall, et al.[8,9] A Beckman Carbonaceous Analyzer* was used. Preliminary homogenization with a Waring Blendor provided representative syringe sampling of whole samples. As the whole acidified sample was further purged with nitrogen gas for five minutes, results were reported as total nonvolatile organic carbon. Acetic acid standards were used for instrument calibration.

4. Total Oxygen Demand

Whole samples were run by the method of Stenger, et al.,[10] using the instrument and techniques described therein. Preliminary homogenization with a Waring Blendor was practiced. Sodium acetate standards were used.

5. Total Hardness

In the field, hardness was determined by EDTA titrimetry according to Standard Methods[4] (Method B, pages 147-152).

Physical Tests

1. Solids

Tests for total suspended and total volatile suspended solids were conducted according to Standard Methods[4] (Methods C & D, pages 424-425). Reeve Angel* 2.4 cm. glass fiber filters, Grade 934AH, were used in lieu of asbestos mats. Gooch crucibles were fired at 600°C, cooled, the mats placed in the crucibles and dried at 103°C for at least 1 hour before initial weighing. At intervals, crucibles with filters were subjected to 600°C furnace temperatures to check for weight loss due to the filter. Total and total volatile solids were determined according to Standard Methods[4] (Methods A & B, pages 423-424).

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*See page 43.

2. Dissolved Oxygen

Measurements were made in situ with a YSI Model 51 Oxygen Meter* equipped with a Model 5103 oxygen/temperature probe. The meter was calibrated against the Azide Modification of the Winkler Method described in Standard Methods[4] (Method A, pages 406-410). The meter was also calibrated against saturated air at the temperature of the test medium.

3. Hydrogen Ion Concentration

All pH measurements were made using a line current Beckman Zeromatic II* equipped with glass and calomel electrodes. Measurements were made on whole-untreated samples.

4. Temperature

Temperature measurements were made with a battery powered thermistor-thermometer.

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*Mention of products and manufacturers is for identification only and does not constitute endorsement by the Federal Water Pollution Control Administration or the U. S. Department of the Interior.

Appendix II

Southwest Indianapolis Sewage Treatment Plant

June 12-21, 1967

June 1967	Plant Performance Data*							
	BOD Concentration (mg/l)			Total Susp. Solids (mg/l)			Overall % Removal	
	Raw Sewage	Pri. Eff.	Final Eff.	Raw Sewage	Pri. Eff.	Final Eff.	BOD	TSS
12	162	92	15	195	70	11	90.7	94.3
13	239	121	6	225	72	16	97.4	93.1
14	200	93	4	245	126	13	98.2	94.5
15	200	80	13	255	86	27	93.7	89.6
16	183	56	7	270	88	20	96.9	92.7
17	158	75	13	115	60	17	91.7	85.6
18	68	60	4	165	70	21	94.8	87.2
19	122	92	22	125	108	21	82.3	83.2
20	169	122	19	375	94	15	88.7	96.0
21	124	89	12	365	80	16	90.7	95.7

June 1967	Operating Data - Activated Sludge Plant					
	Flow		% Ret. Sludge	Air Applied CF/gal.PE	MLSS (mg/l)	RS (mg/l)
	Pri. Eff.	Ret. Sludge				
12	27.2	14.5	53.3	1.7	1,731	4,600
13	27.8	15.0	54.0	2.0	1,897	4,190
14	23.9	14.5	60.8	2.3	1,832	4,150
15	25.2	14.9	59.2	2.3	2,343	4,450
16	14.3**	14.4	101.0	3.6	1,975	3,925
17	20.6**	14.9	72.2	2.5	2,073	2,710
18	20.4**	14.0	68.6	2.4	1,828	3,455
19	28.0	15.3	54.5	1.9	1,636	3,005
20	26.2	14.7	56.0	2.2	1,783	3,585
21	25.1	14.1	56.2	2.7	1,625	3,065

*Based on analysis of 24-hour composite samples consisting of equal portions of grab samples collected hourly by means of automatic samplers. Samples are refrigerated during the compositing period.

**Bypassed waste causing atypical operation.

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GLOSSARY

AT	Aeration tank
FE	Final effluent
ft^3	Cubic feet
Hrs	Hours
mgd	Million gallons per day
mg/l	Milligrams per liter
mg/l-P	Milligrams per liter phosphorus as the element
ml	Milliliters
MLSS	Mixed liquor suspended solids
P	Phosphorus as the element
PE	Primary effluent
ppb	Parts per billion
RS	Return sludge
SNVOC	Soluble nonvolatile organic carbon
TC	Total carbon
TOC	Total organic carbon
TOD	Total oxygen demand
TSS	Total suspended solids